Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-10
DOI: 10.15244/pjoes/185503 ONLINE PUBLICATION DATE:

Original Research

Enhancing the Removal of Diethylhexyl Phthalate from Secondary Effluent Using Guar Gum

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Received: 1 December 2023
Accepted: 28 February 2024

Abstract

With the increasing global concern about environmental issues, researchers are increasingly interested in the use of natural biopolymers to replace inorganic coagulants in order to reduce the use of inorganic coagulants. The removal of diethylhexyl phthalate (DEHP) from secondary effluent by guar gum was investigated and compared with that of alum. Guar gum effectively removed approximately 92.11% of turbidity, 71.47% of total phosphorus, and 54.84% of chemical oxygen demand at a dosage of 3 mg L^{-1}. Further, evaluation and optimization of reaction conditions of coagulation-flocculation process in wastewater treatment by Box-Behnken design of Response Surface Methodology (RSM). The results indicated that a guar gum dosage of 3 mg L^{-1} at pH=7 resulted in the removal of 78.93% of DEHP. SEM showed that guar gum produces flocs with many voids in them compared with alum. This illustrates the greater availability of guar gum in catching and removing particles in suspension and DEHP compared with alum. FTIR indicated that organic matter in the effluent had chemically attached to the coagulants, leading to the removal of the organic matter. Given its nontoxicity and biodegradability, guar gum demonstrates promising potential as a coagulant in wastewater treatment.

Keywords: secondary effluent, guar gum, coagulation, box–behnken design, jar test

Introduction

The removal of emerging contaminants is a critical concern in the wastewater industry. Owing to its low cost, flexibility, and durability, diethylhexyl phthalate (DEHP) has been widely applied in plasticization [1]. Phthalates are causing pollution to the environment due to its easy release during the settlement of plastic products [2]. DEHP is one of the ubiquitous and detectable plasticizers in wastewater. DEHP is listed as a priority pollutant controlled by the U.S. Environmental Protection Agency. DEHP has been reported to affect the developmental health of children, as well as reproductive disorders and endocrine disorders in aquatic organisms [3]. In addition, DEHP is a highly refractory persistent toxic organic compound, leading to the deterioration of ecosystems and human health [4].

Advanced oxidation, ozone oxidation, adsorption and coagulation have been widely used in DEHP removal [5]. However, these techniques are not very efficient due to the operational costs being high. The traditional wastewater treatment process is not effective

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in removing DEHP. To reduce DEHP discharge to the environment as much as possible, further treating the secondary effluent of the wastewater treatment plant is crucial. Coagulation-precipitation method has been extensively applied in water settlement due to its great maintainability and low operating spend [6]. Coagulation is the most commonly used primary treatment method for wastewater. The process is comparatively simple and treats the wastewater through particle agglomeration when the coagulant makes the wastewater suspension unstable. After the suspension becomes unstable in the coagulation process, dense flocculant forms and precipitates, leading to flocculation [7]. However, current studies have primarily focused on the occurrence and removal rate of DEHP. An in-depth understanding of the evolution and reaction between coagulants and DEHP is lacking. Under specific conditions, coagulation is more effective at removing DEHP than traditional processes, but it is also affected by other considerations, such as the sort and dosage of clotting agent [8]. Operating conditions significantly impact coagulation efficiency, and pH, temperature, concentration, and other factors in raw water also play a crucial role in coagulation efficiency [9]. Optimizing these factors will enhance pollutant removal efficiency.

Most inorganic coagulants are expensive and do not degrade naturally [10]. Typically, alum or polyaluminum chloride is widely chosen owing to its proven efficiency and wide availability [11]. Although these chemicals exhibit high coagulation efficiency, their application can release residual toxic aluminum into the aquatic environment. Health risks associated with long-term exposure to aluminum include the accumulation of metals in living organisms, known as bioaccumulation in the human body, particularly in organs [12]. In addition, aluminum residue in water has been linked to brain diseases such as Alzheimer's disease [13] and is considered carcinogenic to humans [14]. Owing to the excessive and long-term use of chemical coagulants, there are many disadvantages, for example, the high cost of procurement, ineffectiveness in low temperature water, harm to people's health, generation of large quantities of toxic sludge and large fluctuations in the pH of treated water [15]. Recently, many natural coagulants have been utilized in wastewater settlement, the most popular being morinda citrifolia and guar gum [16]. With the increasing awareness of the adverse roles of inorganic coagulants, people began to look for sustainable, biodegradable and environmentally amicable coagulants as substitutes or adjuvants for inorganic coagulants [17]. In recent years, the results of the investigation revealing suitable natural coagulants have intensified. Different natural resources, such as Phaseolus vulgaris [17], Durio zibethinus [18], Moringa oleifera [19], and Cassia obtusifolia [20], have been studied. However, because these crude coagulants can be used as edible food resources and medicines, they are receiving increasing attention. Therefore, wild plants that do not compete with the food and pharmaceutical commodity markets are preferred as natural coagulants. Guar gum has a similar structure to other natural coagulants in the literature; therefore, the application of guar gum as a natural non-ionic polymer coagulant was studied.

Guar gum is a seed extract of the legume shrub Cyamopsis tetragonoloba, commonly found in the Indian subcontinent, the United States, Australia, and Africa [21]. Guar gum is a direct-chain galactomannan derived from the seed of the guar plant [8]. The development of sustainable waste disposal technologies is closely linked to producer responsibility and consumer responsibility. Therefore, policymakers and local authorities must choose environmentally friendly waste treatment technologies and optimize treatment processes to minimize waste [22]. Owing to its stable nature and ease of processing into powder, guar gum, as a coagulant, can enhance the binding ability of suspended particles in sewage, making them easier to precipitate. Compared with traditional chemical coagulants, guar gum as a sewage coagulant offers unique advantages. Therefore, guar gum as a coagulant exhibits great application prospects in wastewater processing. The aim of this research was to investigate the feasibility of using guar gum as a coagulant aid in wastewater treatment. The three objectives were (1) a comparison among two types of coagulants, guar as a natural coagulant as well as alum as chemical coagulants, was also carried out, (2) the characterization of flocs, (3) determination of the optimum coagulating condition of the guar gum in wastewater treatment. The characterization studies included surface morphology analysis, functional group evaluation, and zeta potential analysis. Finally, the experimental design (RSM) was used to evaluate the effects of wastewater treatment, determine the behavior of guar gum in the treatment process, and understand its action mechanism in the water treatment process.

Experimental

Chemical Preparation

Reagent grade chemicals were obtained from Anpel (Shanghai, China). Alum ($KAl(SO_4)_2 \cdot 12H_2O$, 500g, ≥99.5%) and guar gum (100g, ≥99.5%) were used as coagulants. A solution of alum was prepared through the dissolution of 2 g in 1 L of distilled water, with simultaneous preparation of guar gum solution through the dissolution of 1 g of powder in 1 L of distilled water. Fresh solutions were prepared prior to the experiment to prevent mold growth. The target antibiotic used in the experiment was DEHP, which was purchased from Anpel, and the reagent was of analytical grade (purity > 95%). Additionally, the solid-phase extraction (SPE) cartridge (Waters, c18, 6 mL, 500 mg) was purchased from Anpel (Shanghai, China).

Coagulation and Flocculation Test

The tests were fulfilled making use of a Jar experiment apparatus. The mixed process was divided into three stages. The speed of the propeller was set to 200 revolutions per minute (rpm) for 5 minutes during the fast mixing phase. After 1 minute of flash mixing, flocculant was added to the sample. This was followed by two other phases of slow speed, each lasting ten minutes, at 60 rpm and 40 rpm, respectively. After mixing, the flocculant was permitted to settle for thirty minutes. Getting the upper clear after thirty minutes of precipitation was used for the extraction and analysis of contaminants. And all the jar test experiments were conducted at room temperature (22°C ± 2°C).

Experiments for Effects of the Dosage

Effluent was collected from the secondary sedimentation tank of a sewage treatment plant. Preparation of water samples and transfer to 1 liter jars. The dosages of alum were 1 g L^{-1}, 1.5 g L^{-1}, and 2 g L^{-1}, while the dosages of guar gum were 2 mg L^{-1}, 3 mg L^{-1}, and 4 mg L^{-1}. The measurement indicators included TP, chemical oxygen demand (CODcr), turbidity, and DEHP.

$$\text{Turbidity}, (100\%) = \frac{\text{Ti}-\text{Tf}}{\text{Ti}} \times 100 \quad (1)$$

$$\text{TP}, (100\%) = \frac{\text{Pi}-\text{Pf}}{\text{Pi}} \times 100 \quad (2)$$

$$\text{CODcr}, (100\%) = \frac{\text{Ci}-\text{Cf}}{\text{Ci}} \times 100 \quad (3)$$

where the symbol i represents the influent parametric, f denotes the effluent parametric, T denotes turbidity, C represents the COD concentration, and P denotes TP.

Experimental Design of Guar Gum Response Surface

In this research, Design Expert® 13.0 Software was used for the design of experiments. The Box–Behnken design, a common experimental design for RSM, was selected and implemented. RSM is primarily used for designing experiments, as it reduces amounts of scheduled experiments and allows for assessing the relationship between importation considerations and responses [23, 24]. It is also valuable for quantifying the relations between one or more responses and considerations [25]. In this study, the three operating parameters of the response surface were dosage, pH, and mixing speed. The number of runs of the three-factor (k) experiment is determined by the formula 2k(k−1)+ 5 [26]. This resulted in the Box-Behnken design simulating about 17 experiment runs (Table 2). In general, the response surface function is as follows:

$$y = f(X1, X2, X3,...,Xk) \quad (4)$$

where y represents the whole system, and xi represents the considerations under study. In order to optimize coagulation, RSM reunification statistics analysis and a quadratic equation model were utilized and implemented. The quadratic equation model is represented in Equation (5) [23, 27].

$$yi = \beta_0 + \sum_{i=1}^{k} \beta iXi + \sum_{i=1}^{k} \beta iiXi^2 + \sum_{i=1}^{k-1} \sum_{j=1}^{k} \beta ijXiXj + \varepsilon \quad (5)$$

where yi on behalf of the response, xi represents the investment factor, β0, βii (i = 1,2,…,k), and βij (i = 1,2,…,k; j = 1,2,…,k) are unknown parametric, and ε is a stochastic error. Following the completion of this test, verification analysis was conducted. During this point, optimum technological conditions recommended by the Box-Behnken (BB) design are adopted. The rejection and error rates for each response were recorded and evaluated.

Sample Collection

A 1.0 L of sample was taken and filtered through a 0.45 μm glass fiber membrane and transferred to a glass vial. SPE was used to enrich the aqueous samples. The solid phase extraction column (Waters, C18, 6 mL, 500 mg) was conditioned with 6 mL of hexane, 6 mL of methanol, and then 6 mL of ultrapure water. Then, the filtered water samples through the pre-settled solid phase extraction column at 10 mL min^{-1}. After a nitrogen stream was passed through the system for 5–10 minutes, 8 mL (ethyl acetate: dichloromethane = 1:1) was used to elute DEHP from the cartridges. Prepared anhydrous sodium sulfate was used for dehydration. Extracts were dried under a gentle flow of nitrogen stream and redissolved in 1 mL of hexane, mixed, and passed through a 0.22μm organic filter membrane. The final withdrawal samples were stored at 20 degrees below zero until analyzed.

Instrument Analysis

TP, CODcr, and turbidity were determined according to the Method of Water and Wastewater Monitoring (fourth edition). The zeta potential of supernatants and secondary clarifier effluent samples was surveyed making use of a Malvern Zetasizer Nano ZS, and the measurement was measured three times at 25°C.

The DEHP samples were analyzed by gas chromatography-mass spectrometry(GC-MS) on a DB-5MS capillary column (film thickness 30m × 0.25 mm × 0.25 μm). Gas chromatography operating conditions are as follows: The oven temperature was initially set at 60°C and held for 1 minute. Then, it was increased to 220°C at 20°C min-1 and held for 1 minute. Subsequently, the temperature was then increased to 250°C for 1 min at 5°C min^{-1} and finally to 280°C for 7.5

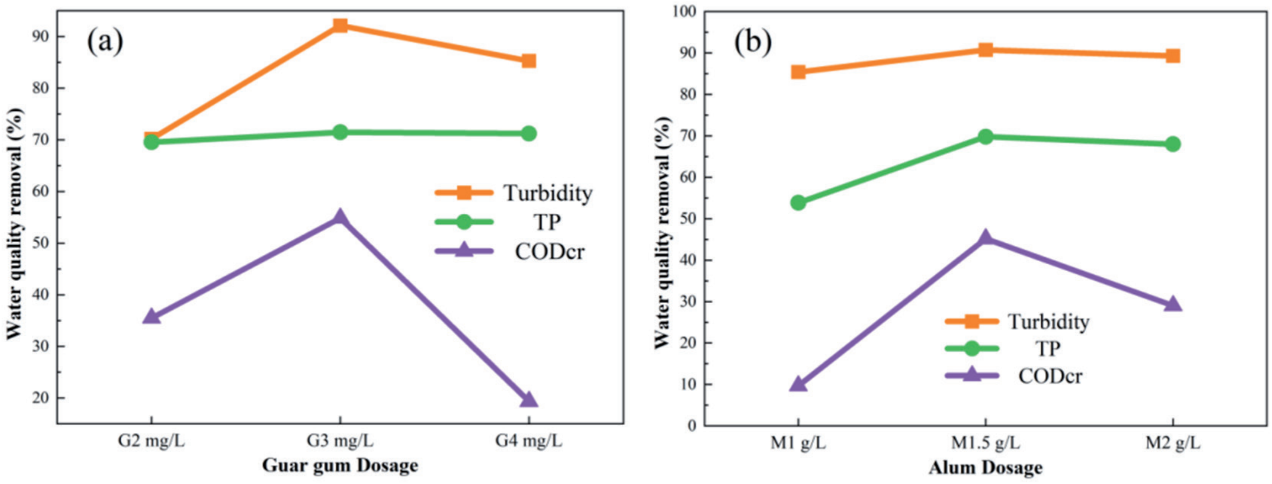


Fig. 1. The removal of water quality in secondary effluent making use of (a) guar gum ;(b) alum at different dosages.

min at 8°C min^{-1}. The injection temperature was 260°C and the sample volume was 1 μL (no splitting).

The graphics of flocs after processing were obtained using a scanning electron microscope coupled with an SEI detector (JEOL JSM-7001F). The FTIR spectra of the flocs with secondary effluents were obtained by an FTIR-Spectrum 400, Perki-n Elmer spectrophotometer.

Data Handling and Analysis

The removal of water quality indicators and DEHP was statistically and graphically analyzed using Microsoft Excel 2019 and Origin 2021 software. Design of experiments using Design Expert 13 software, mathematical modeling and data analysis. The Box-Behnken design was adopted to enhance the operating parametric of DEHP removal in guar gum. The three key operational considerations optimized were coagulation volume, the value of effluent pH, and mixing speed in this study, with median values of 3 mg L^{-1}, 7, and 200 rpm, respectively. The Box-Behnken design is a ball-shaped layout known for its great predictability, which demands less experimentation than other design types. A set of second-order designs was performed five times.

Results and Discussion

The Removal of Conventional Water Quality Using Two Types of Coagulants

The mean values of secondary discharged water, such as turbidity, TP, and CODcr were 7.95 NTU, 0.778 mg L^{-1}, and 46.66 mg L^{-1}, separately.

The removal of water quality from secondary effluent making use of two types of coagulants at pH= 7 is shown in Fig.1. The coagulation precipitation is employed in a widespread manner as a pre-processing methodologies in sewage settlement plants to effectively remove turbidity from source water [9, 28, 29]. Guar gum dosages were 2 mg L^{-1}, 3 mg L^{-1}, and 4 mg L^{-1}. Approximately 92.11%, 71.47%, and 54.84% of turbidity, TP, and COD, respectively, were effectively dismissed making use of guar gum coagulant at 3 mg L^{-1}. Turbidity, TP, and COD removal from secondary effluent initially increased and then declined as the guar gum coagulant was added from 2 to 4 mg L^{-1}. The zeta of the secondary effluent was -11.4 mV, then it decreased to -12.8 mV (Table 1) after the addition of guar gum. So, electric charge neutralization did not operate on coagulation-flocculation; instead, guar polymer bridging is the primary method for secondary effluent removal [8]. Surpassing the optimal dosage, the removal rate begins to decline, probably owing to enhanced passive impact between the flocculant and the suspension of particulate matter, suppressing floc production [30]. Turbidity, TP, and COD removal from secondary effluent initially enhanced and then decreased as the dosage of alum was added from 1 to 2 g L^{-1}. Zeta potential of the secondary effluent was -11.4 mV, and after the addition of alum, it increased to -2.22 mV (Table 1). Therefore, charge neutralization plays a role in coagulation-flocculation. However, excessive alum can cause colloidal particles in the liquid to absorb a large number of particles with opposite electrical properties, leading to a stable state that is difficult to settle and resulting in a decrease in removal efficiency.

In terms of turbidity and TP, guar gum and alum had similar removal effects, with turbidity reaching ~90%. Regarding COD removal, owing to guar gum being a biopolymer, it exhibits a better organic matter removal effect than the inorganic coagulant (alum). In the context of the removal of secondary effluent, the removal mechanism of biopolymers (guar gum) is significantly different from that of chemical coagulants (alum). The role of chemical coagulants is to destabilize colloidal particles through charge neutralization, while biopolymers primarily rely on the polymer's affinity for suspended particles and act according to the polymer bridging principle.

Table 1. Zeta potential of the effluent before and after adding flocculants.

Coagulant	Dose	pH	Zeta potential(mV)
Guar gum	3 mg L^{-1}	4	-7.5
		7	-12.8
		10	-11.9
Alum	1.5 g L^{-1}	4	-7.73
		7	-2.22
		10	-15.6
Effluent			-11.4

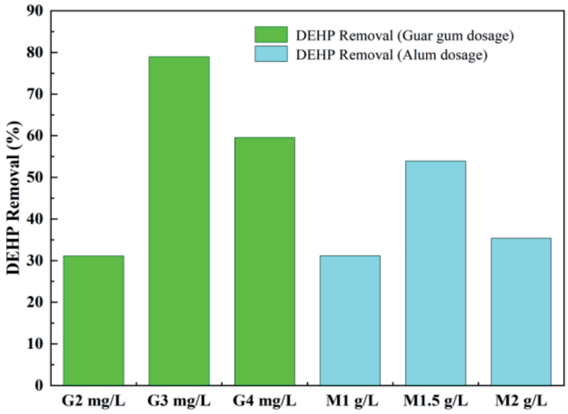


Fig. 2. The removal of DEHP in secondary effluent with different dosages of coagulants.

DEHP Removal by Alum and Guar Gum

Effectiveness of alum consumption on DEHP dislodge was explored under pH 7. The starting pH of the sewage was elected within the coverage of 6–8. This coverage was selected depending on research by [31]. This study found that alum was effective in reducing pollutants in the pH realm of 6-8. The results of DEHP removal via alum treatment in secondary effluent are shown in Fig. 2. The DEHP removal rate decreased slightly with the increase in alum dose. Additionally, the zeta potential of the secondary outlet was -11.4 mV and increased to -2.22 mV after alum addition (Table 1). This increase in zeta potential was due to the positively charged nature of aluminum ion hydrolysates, and studies have indicated that charge neutralization plays a significant role in alum coagulation-flocculation [32]. Therefore, electrical neutralization was the primary process. However, the removal rate decreased when the optimal dosage was exceeded. When the pH exceeded 9.00, electrical neutralization was restricted [27]. Studies have indicated that excessive alum can cause colloidal particles in the liquid to adsorb a large number of particles with opposite electrical properties, leading to a stable state that is difficult to settle, resulting in reduced removal efficiency [8]. The DEHP results of guar gum treatment in secondary effluent are also shown in Fig. 2. The removal rate increased within a certain range, however, with the increase of dose, DEHP removal rate decreased slightly. Guar gum is a type of galactomannan. Its role is to build Bridges between particles and promote coagulation to form flocculants [21]. However, the excessive addition of guar gum can lead to increased repulsion energy between the polymer and suspended particles [33]. In terms of DEHP, guar gum and alum had similar removal effects. The removal rate increased within a certain range, but when the optimal dosage was exceeded, the removal decreased.

Flocculation Studies

Guar Gum Response Surface Experiment

Given that guar gum outperformed alum in DEHP removal, three operating parameters of guar gum flocculation studies were optimized. ANOVA results for the removal of DEHP are presented in Table 3. The equations were developed for DEHP removal using the following formula.

$$\text{DEHP removal} = -245.75000+48.58333\times\text{Dose}+50.16667\times\text{pH}+0.688333\times\text{Mixing Speed}-0.333333\text{Dose}\times\text{pH}+0.030000\text{Dose}\times\text{MixingSpeed}-8.50\times\text{Dose}^2\ 3.66667\times\text{pH}^2-0.002200\times\text{Mixing Speed}^2 \quad (6)$$

ANOVA also evaluates the variations between groups of data to determine if their mean values are equal [27]. The ANOVA returning modeling demonstrates that quadratic modellings are eligible for predicting DEHP removal, as evidenced by Fisher's F-Test (F-model = 384.56) with an extremely low probability (P-value < 0.0001). There is just a 0.01% chance that a "Model F-value" this large can occur because of the noise. As can be seen from Table 3, it can be observed that the anticipated R^2 value (0.998) agrees well with the adjusted R^2 (0.995). The adequate

Table 2. Design of RSM for enhancement of Guar gum for secondary effluent.

Run	Dose (mg/L)	pH	Mixing speed (rpm)
1	2	7	250
2	2	4	200
3	3	7	200
4	3	10	150
5	4	7	150
6	3	7	200
7	3	10	250
8	3	4	150
9	2	10	200
10	2	7	150
11	3	7	200
12	3	7	200
13	4	4	200
14	4	10	200
15	4	7	250
16	3	4	250
17	3	7	200

precision value of 49.145 indicates adequate precision for DEHP removal.

Effect of Dosage and Mixing Speed

Fig. 3a and Fig. 3b demonstrate the response surface plots for DEHP removal in response to variations in the dosage of guar gum, pH, dose and mixing speed, respectively. DEHP removal slightly decreased with increased dosage. According to [34], crude polymers generally destabilize pollutant grains through adsorption and inter-particle bridging. The role of guar gum is to form a bridge between the particles, facilitating aggregation to form flocculates [21]. However, excessive amounts of guar gum can raise the exclusion energy between polymer and suspended particles, leading to a decline in DEHP removal rate. The lower DEHP removal rate at higher doses may be due to the resuspension of solids at elevated concentrations [30]. At the same time, the mixing speed played a prominent role in achieving elevated coagulation properties during the settlement as well. Initial rapid mixing is essential to assure a uniform distribution of coagulants and suspensions. However,

Table 3. The statistical modeling obtained from the ANOVA for enhancement of DEHP removing from the secondary effluent.

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Mode	5438.76	9	604.31	384.56	<0.0001	Significant
A-Dose	12.50	1	12.50	7.95	0.0258	
B-pH	98.00	1	98.00	62.36	<0.0001	
C-Mixing Speed	4.50	1	4.50	2.86	0.1344	
AB	4.00	1	4.00	2.55	0.1546	
AC	9.00	1	9.00	5.73	0.0479	
BC	25.00	1	25.00	15.91	0.0053	
A^2	304.21	1	304.21	193.59	<0.0001	
B^2	4585.26	1	4585.26	2917.89	<0.0001	
C^2	127.37	1	127.37	81.05	<0.0001	
Residual	11.00	7	1.57			
Lack of Fit	5.00	3	1.67	1.11	0.4428	Not significant
Pure Error	6.00	4	1.50			
Cor Total	5449.76	16				
Std. dev.	1.25		R-squared	0.9980		
Mean	56.88		Adj R-squared	0.9954		
C.V.%	2.20		Pred R-squared	0.9836		
Press			Adeq precision	49.1450		

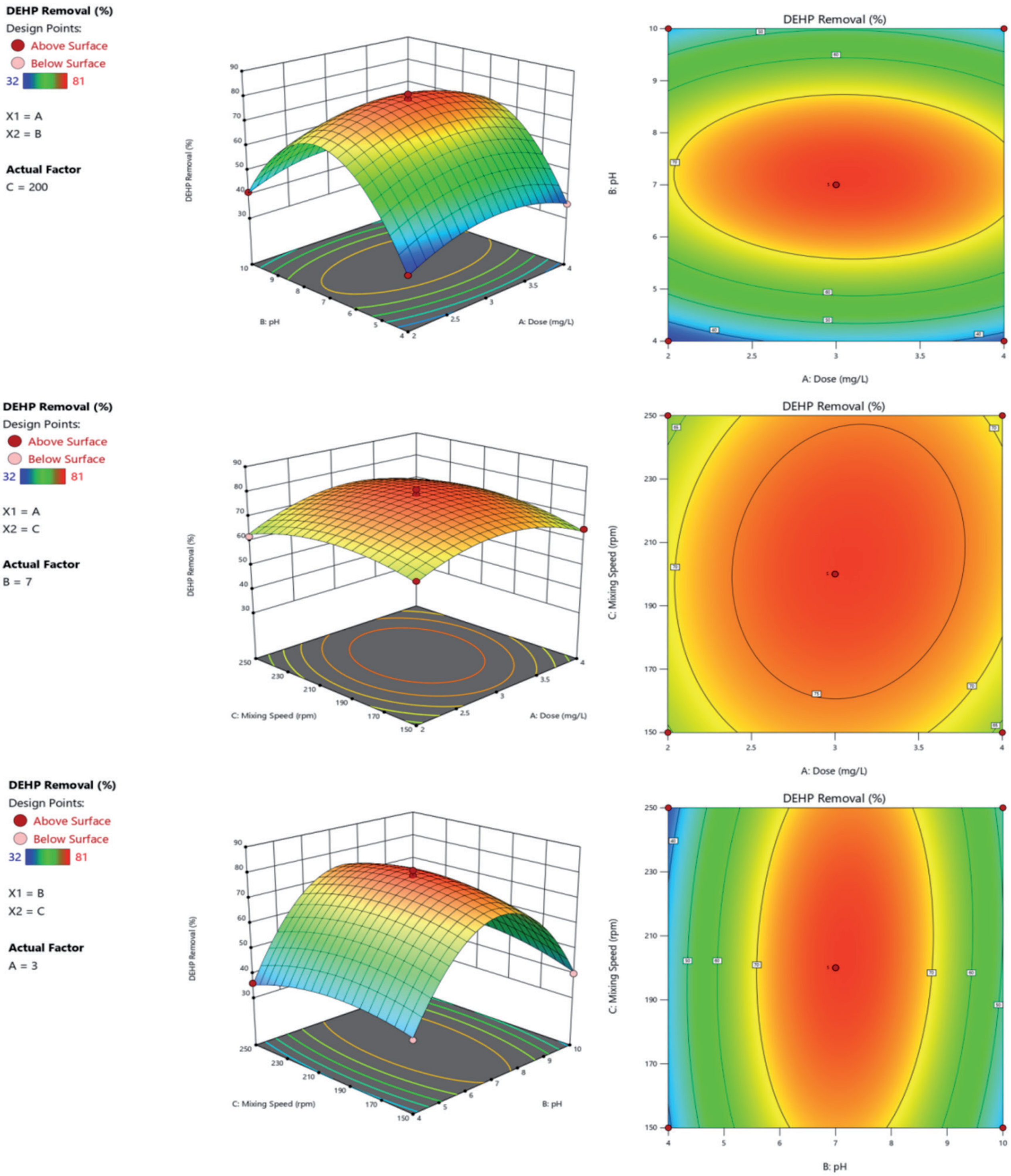
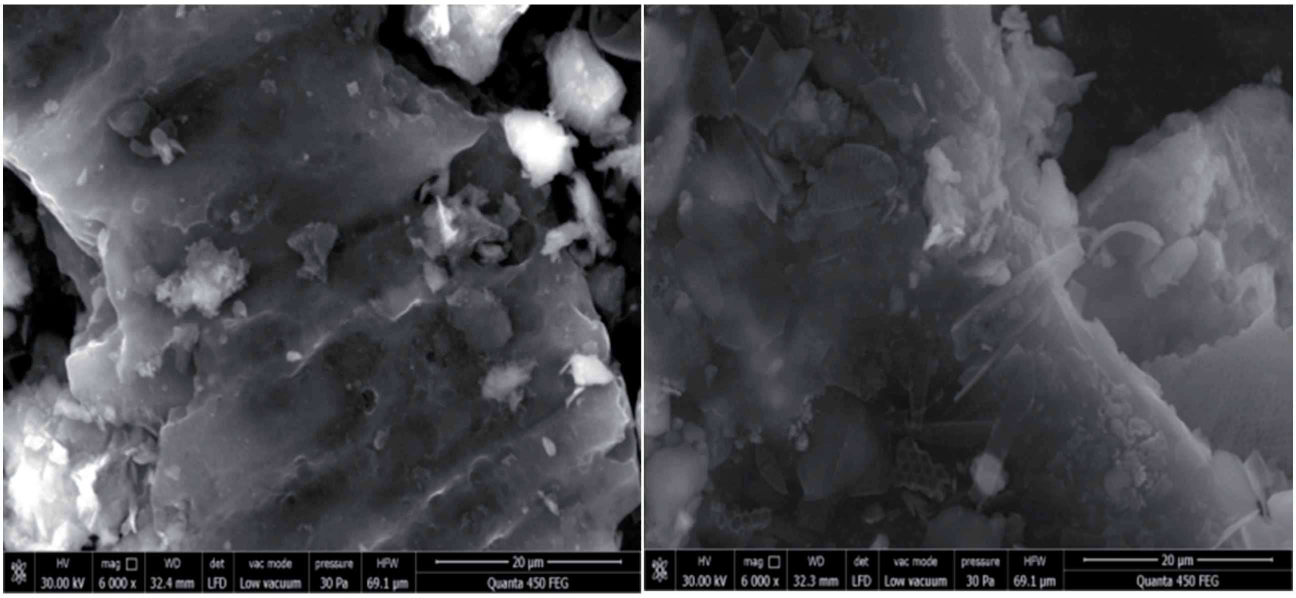


Fig. 3. 3D response surface plot and contour plot of DEHP removal: Effects of (a) dosage; (b) mixing speed; (c) pH.

during mixing, high speeds can lead to floc sabotage owing to surface corrosion [26].

Effect of pH

The pH of wastewater is one of the crucial considerations influencing the flocculation process [30]. The pH is an important factor that may affect the nature of the functional groups of pollutants and existing forms of coagulants [35].As can be seen from the response surface diagram in Fig. 3c, DEHP removal rises first and then decreases when the pH value increases. When pH = 7, the removal rate was the highest, and the removal rate of DEHP was 3 mg L^{-1}. [36] showed that more adsorption and bridging occurred at high pH levels. When the concentration was saturated, a process known as “sweep-floc coagulation” occurred. Therefore, the removal rate of DEHP decreased after the optimal



a

b

Fig. 4. (a) SEM micrographs of secondary effluent guar gum flocs; (b) SEM image of secondary effluent alum flocs.

pH was exceeded. Besides, high pH values were more appropriate for pollutant removal using Cassia fistula gum [37]. In addition, plant-based coagulants are most effective at a pH range of 7 to 10 [38].

Flocs Characteristics

The Surface Morphology of Flocculants

The scanning electron microscopy (SEM) micrographs are shown in Fig. 4. Compared with alum floc, guar gum floc has more voids. According to SEM of the guar gum flocs, pollutants were adsorbed on the active site on the porous surface of guar gum. The capacity of guar gum in the sorption course of events is attributable to its affinities for coupling to polymer groups [33]. This explains why guar gum was more effective in removing DEHP. Additionally, the form of sludge after the settlement with crude coagulants. For instance, guar gum has nitrogen, sulfur, phosphorus, and other essential plant nutrients, making it suitable for use as fertilizer [39]. Replacing traditional inorganic coagulants with natural guar gum coagulants is considered “generally recognized as safe,” and the application of guar gum will not disturb the ecosystem [40].

Structural Characterization of the Flocculations

Fig. 5 describes the FTIR spectroscopy of guar gum powder, guar gum flocs, alum flocs, and secondary effluent. FTIR studies have shown that there is a chemical reaction between the cation and the lively group, leading to DEHP removal. The infrared (IR) spectroscopy of guar gum powder featured peaks near wave numbers 3377 cm^{-1}, 2904 cm^{-1}, 1644 cm^{-1}, and 1004 cm^{-1}, which indicate the vibrations of -OH, C-H, C-C, and C-F, respectively. Similar peak patterns indicative of stretching vibration also occurred in the polymer compounds. The highest peak at 2925 in powder demonstrates hydrocarbon extension of fatty acids and fatty structures commonly found in lipids [41]. The C=O bond is stretched between 1800 and 1600 cm^{-1} [42]. This suggests that the existence of dissociated carboxyl groups can aid the solidification procedure by producing ion bridges and binding sites for bivalent metal ions [43]. The infrared spectrum of the secondary effluent guar gum floc was homologous to that of the secondary effluent, showing peaks near wavelengths 3365, 1652 and 1044 cm^{-1}, which represent structural foundation vibration of -OH, C-C, and C-F. In alum flocs with the secondary effluent, some peaks occurred near wavelengths 3384, 1664, and 1060 cm^{-1}, implying the existence of -OH, C-C, and C-O. Though the infrared spectroscopy of guar gum flocculations with the secondary effluent was homologous to the secondary effluent as well as guar gum powder, the wave number of the peak is shifted several times, owing to hydrogen bond formation. The disassociate active hydroxyl group in the skeletons of the guar gum may be replaced by the carbonyl group, allowing DEHP to be removed.

Conclusions

In order to prove the feasibility of guar gum as coagulant for coagulation sedimentation-based water treatment, the effects of the amount of guar gum and its operating conditions on minimizing DEHP residues were investigated experimentally. The coagulation effect

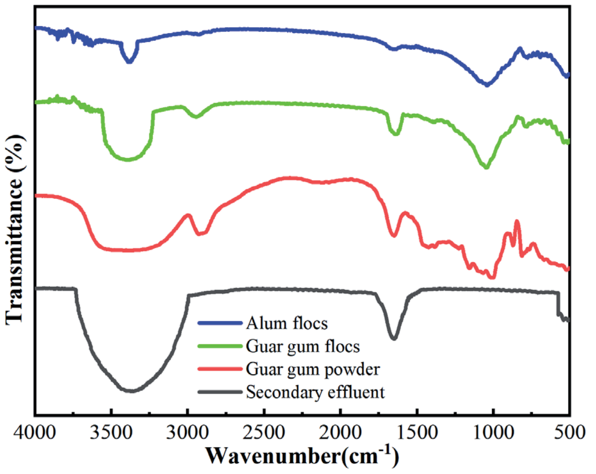


Fig. 5. FTIR spectroscopy of secondary effluent, guar gum powder, guar gum flocs, and alum flocs.

of guar gum was superior to that of alum. Guar gum effectively removed approximately 92.11% of turbidity, 71.47% of total phosphorus, and 54.84% of chemical oxygen demand at a dosage of 3 mg L^{-1}.RSM was employed to optimize the DEHP removal rate, and the optimal conditions were determined, with a dosage of 3 mg L^{-1} of guar gum at pH of 7, resulting in a DEHP removal rate of 78.93%. Box-Behnken experimental design and analysis of variance demonstrated the significance of design parameters on DEHP removal rate. The SEM of guar gum flocs confirmed the efficacy of flocculation, as the flocculates formulated by guar gum were dense and had more voids, promoting the settlement and removal of accumulated pollutants. FTIR analysis also revealed the hydrogen bonds or bridges properties that contributed to floc production during the treatment. The harmlessness of guar gum reduces the risk of contaminating wastewater compared to other chemicals such as alum as coagulants. Given its abundance and ubiquity, guar gum is a promising natural resource that can replace artificial chemicals for wastewater treatment.

Acknowledgements

This research was supported by the Program of the Department of Science and Technology of Jilin Province (No. 20220508116RC).

Conflict of Interest

The authors declare no conflict of interest.

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