Enhancement of Primary Sedimentation Using Natural Coagulants in Wastewater Treatment Plants

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DOI: https://doi.org/10.5281/zenodo.14040917

Published Date: 05-November-2024

Abstract: **Coagulation and flocculation are used in wastewater treatment to control the produced waste. Chemical coagulants have limited success in wastewater treatment because of their deficiency of consistency in meeting discharge requirements, high costs, handling, and disposal of huge volumes of sludge resulting from the increase of chemicals, and multiple operating problems. Instead of chemical coagulants, the natural ones can also be successfully used. Samples of wastewater were collected from the effluent of the grit removal chamber at the Belkas wastewater treatment plant, which is located in Egypt to study the enhancement of the performance of primary sedimentation. Experiments were conducted at various doses of Moringa Oleifera Seeds Powder (MOSP), Banana Peel Powder (BPP) and Mango Seeds Powder (MSP) using jar test equipment. Wastewater quality parameters were measured before and after treatment to evaluate the removal efficiency of turbidity, TSS, BOD_5, and COD. Using response surface methodology (RSM) to analyze the results of removal efficiency. Results showed that optimum operating conditions for (MOSP) at 720 mg/l and 45 min of sedimentation increased the removal efficiency of turbidity, TSS, BOD_5 and COD to 97.1 %, 99.3%, 94.67%, and 85.1% respectively. However, the optimum operating conditions for (MSP) at 480 mg/l and 45 min of sedimentation increased the removal efficiency of turbidity, TSS, BOD_5, and COD to 73.55 %, 62.57%, 59.87%, and 51.52% respectively. The optimum operating conditions for (BPP) at 105 mg/l and 45 min of sedimentation increased the removal efficiency of turbidity, TSS, BOD_5, and COD to 66.98 %, 57.93%, 58.76%, and 44.09% respectively. The removal efficiency will be reduced due to using doses of natural coagulants that exceed the optimum dose of each coagulant.**

Keywords: **Banana Peel, Mango Seeds, Moringa, Natural Coagulants, Primary Sedimentation, Wastewater.**

I. INTRODUCTION

Water covers the planet Earth more than 70 % of its surface while 97 % of Earth's water is occupied by the oceans. So, the total freshwater is only 3%. There are 65 % of this water is in the ice caps of mountains and 30.2% in groundwater. Hence, there are only 1.3 % of water available for human use [1]. One of the major crucial factors for economics is water. The environment, human health, and ecosystems require high-quality water. the increasing harmful effect on the quality of water due to the increase in agricultural, urbanization and industrial manufacturing [2] [3]. In the last few decades, the amount of generated wastewater in domestic and industrial has been increased [4]. To obtain the optimum condition of water quality using wastewater treatment, the treatment of wastewater becomes necessary before discharging it into water bodies [5]. Before effluent wastewater into water bodies, the wastewater was treated using suitable treatment technologies[3]. Effective domestic wastewater resources treatment and pollution prevention are required to guarantee compliance with environmental regulations and resource reuse [6]. Wastewater treatment consists of three main stages physical, chemical and biological that reduce the contamination [7]. The purpose of treating sewage and sludge is to discharge it into the environment and reuse it [7]. It can be removed about 50% TSS and 30% BOD at the primary sedimentation, which is the first stage in wastewater treatment. Primary sedimentation performance can be improved by using coagulants. The processes of coagulation and flocculation are essential components of the majority of water and wastewater treatment regimens. Coagulation flocculation is widely used for water and wastewater treatment as it removes turbidity, organic matter, turbidity, suspended solids, and colour [8]. The traditional coagulation technique involved the blend of divalent cationic chemical compounds, such as $FeCl_3$ and $Al_2(SO_4)_3$, which have demonstrated detrimental effects on health and the environment. polyaluminium chloride, ferric chloride, and calcium carbonate are used as inorganic coagulants in wastewater treatment [8].Using chemical compounds as coagulants such as Alum can lead to a high residual of alum in wastewater that decreases the pH of wastewater due to the acidic nature of Al3[9]. Meanwhile, the produced sludge gathers in the environment due to the using aluminium salts for treatment [10]. The best alternative to reduce environmental pollution is Transition from chemical coagulants to natural ones [11]. Applying natural coagulants instead of chemical ones reduces environmental pollution and health hazards[12]. In recent years, research has investigated natural coagulants produced by plants like Moringa oleifera [13], Jatropha curcas [14], banana peels [15], and bagasse [16]. Table 1 summarize the applications of natural coagulants in wastewater treatment.

Table 1: Applications of natural coagulants in wastewater treatment

Types of wastewater	Natural coagulant	Removal efficiency	References
Paper mill industry	Moringa oleifera seed	Turbidity: 97.1% COD:92.7%	[17]
Concrete plant	Moringa oleifera seed	Turbidity: 99.9%	[18]
River water	Moringa oleifera seed	Turbidity: 62.5% Coliform bacteria: 70-93.3% Mesophilic bacteria: 93.7-98.3%	[19]
POME	Moringa oleifera seed	TSS: 95.4% Turbidity: 88.3% NH4-N: 89.8% Color: 90.2% Oil and grease: 87.1%	[20]
Paint industry	Cactus	Color: 88.4% COD: 78.2%	[21]
Confectionary	Cactus	TSS: 92.2% COD: 95.6%	[22]
Synthetic wastewater	Jatropha curcas seed	Turbidity: 99.6% Sedimentation time: 20 min Sludge volume: 40 mL/L	[23]

The purpose of this research is to analysis the procedure optimization using response surface methodology (RSM) for the Enhancement of Primary Sedimentation Performance in Wastewater by using natural coagulants that were extracted naturally. Moringa Oleifera Seeds Powder (MOSP), Banana Peel Powder (BPP) and Mango Seeds Powder (MSP).

II. MATERIALS AND METHODS

A. Wastewater Source

Wastewater samples used in the jar test were collected from Belkas wastewater treatment plant which is located in Egypt, after the effluent of the grit removal chamber as shown in Fig. 1.

Fig. 1: The effluent of the grit removal chambers (Samples collection)

The selected samples were collected freshly every day and evaluated at the Belkas wastewater treatment plant laboratory. The wastewater samples characteristics are shown in Table 2.

Table 2: Wastewater samples characteristics

Parameter	Range
pH	6.8-7.7
Turbidity (NTU)	80-120
TSS (mg/l)	170-200
COD (mg/l)	320-430
BOD (mg/l)	130-190

B. Natural Coagulants Preparation

Three natural coagulants were used (MOSP), (BPP) and (MSP). Moringa oleifera seeds were manually removed from the husk around each seed. Then use an electric blender to grind the kernel into a fine powder. This study utilized a 5% concentration (5 gm of powder in 100 ml tap water). At room temperature, the entire solution was blended for 10 minutes with a magnetic stirrer. The suspension was subjected to filtration using 474-grade filter paper. The filtrate solution was then utilized as a coagulant [24]. The banana peels were collected from household use. The banana peels were subjected to solar drying for a week, followed by oven-drying at 60°C for 20 minutes. Using a mortar pestle, the dried peels were crushed into fine powder. The 1 gm of fine powder was mixed with 100 ml of distilled water and stirred up for 15 - 45 minutes on a magnetic stirrer and the results were filtered to produce aqueous extracts of banana peels [25]. Mango seeds were gathered from household uses. The seeds were shelled handily and converted into powder using a blender. The powder generated from the blender was filtered through a 52-mesh sieve with a300-µm opening size. Using 5 gm of produced powder with 100 ml to create a solution with 5% concentration. The mixture of each coagulant was agitated for 5 min at 200 rpm to extract active coagulation components. To remove suspended particles, using filter paper (grade 103, 8 µm) to be subjected to the mixture [26]. Fresh coagulant solutions were prepared on the same day as the trials.

C. Response Surface Methodology (RSM)

Using Design Expert Software for the statistical design of experiments and data analysis. CCD and RSM were exercised to optimize the impact of natural coagulant dose and time of sedimentation on TSS, COD, BOD_5 and turbidity. The variation of coagulant dosage was based on the type of coagulant and the time of sedimentation ranged from 15-45 minutes. The CCD design shows that to optimize the two input parameters, a total of 19 tests are required. Table 3 shows the Central Composite Design (CCD) experimental plan for the MOSP, BPP, and MSP natural coagulants considering the different ranges of the operating conditions.

Table 3: experimental plan for using natural coagulant

Experimental	Time of sedimentation min	Coagulant type		
		MOSP mg/L	MSP mg/L	BPP mg/L
1	45	500	300	220
2	15	0	0	80
3	15	500	300	160
4	30	500	0	60
5	30	550	100	140
6	45	0	0	200
7	30	200	900	0
8	15	100	400	220
9	15	550	800	180
10	15	1000	1000	40
11	45	100	800	100
12	15	1100	1100	0
13	45	1000	900	40
14	45	1100	1100	160
15	30	300	300	20
16	45	550	550	0
17	30	900	550	180
18	30	800	700	100
19	30	600	1100	220

D. Experimental Works Procedures

All experiments were tested using a jar test developed by VELP in coagulation, flocculation, and sedimentation all experiments. Three times of each experiment was tested and the average was taken. Wastewater samples were collected freshly and were distributed among the six jars after thorough mixing, as shown in Fig. 2. 500ml of wastewater samples was added in each jar in addition different Coagulant dosages were added according to the experimental plan. To guarantee the distribution of the natural coagulants uniformly, the mixture was mixed for 1 min at 120 rpm. Then, to form the flocs, the mixture was subjected to slow mixing for 20 min at 20 rpm [5]. Subsequently, a quiet settlement for a different period was permitted. The samples of the supernatant were taken from the middle of the beaker and examined for the various parameters (turbidity, TSS, BOD, COD and pH) according to the methodology of the 21st edition Standard Methods for the Examination of Water and Wastewater (APHA, 2005), at the end of the settling time. All experiments were tested at the lab room temperature 26±2°C. Turbidity, TSS, COD and BOD removal were evaluated based on eq No. 1, 2, 3, and 4 respectively.

$$Turbidity\ removal\ \% = \frac{Initial\ turbidity - Residual\ turbidity}{Initail\ turbidity} * 100\#(Eq.1)$$

$$TSS\ removal\ \% = \frac{Initial\ TSS - Residual\ TSS}{Initail\ TSS} * 100\#(Eq.2)$$

$$COD\ removal\ \% = \frac{Initial\ COD - Residual\ COD}{Initail\ COD} * 100\#(Eq.3)$$

$$BOD\ removal\ \% = \frac{Initial\ BOD - Residual\ BOD}{Initail\ BOD} * 100\#(Eq.4)$$

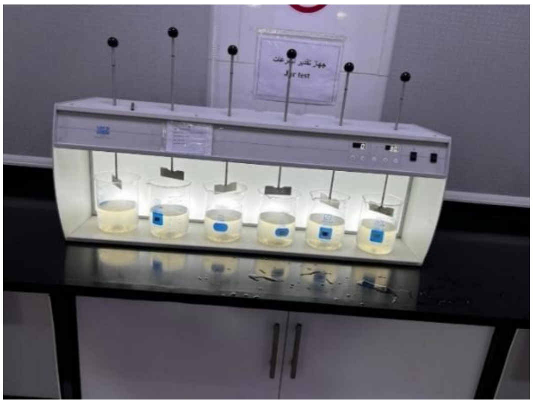

Fig. 2: Jar test

III. RESULTS AND DISCUSSIONS

A. Effect of (MOSP) Dose and Time of Sedimentation on The Turbidity, TSS, BOD5 and COD Removal

Fig. 3 (a, b, c, and d) shows the relation between dose and time of sedimentation on turbidity, TSS, BOD_5, and COD has been analyzed using Response Surface Methodology (RSM). As shown in Fig. 3, the increase in the time of sedimentation from 15 min to 45 min and the dose from 100 mg/l to 720 mg/l led to a significantly greater rate of pollution removal. The results are detailed in Table 4.

Fig. 3 (a, b, c, and d) show the turbidity, TSS, BOD_5 and COD removal rates respectively. At MOSP dose of 720 mg/l and time of sedimentation of 45 min, the turbidity, TSS, BOD_5 and COD removal rates are 97.1 %, 99.3%, 94.67%, and 85.1% respectively. The addition of more coagulants to wastewater will result in more active coagulant sites that will attract and absorb contaminants. In addition, adding coagulants to wastewater neutralizes the electrical load to zero zeta potential, and allows contaminants to be attracted and absorbed by the coagulants [27].

However, using MOSPE dose greater than 720 mg/l leads to a decrease in the removal rate of turbidity, TSS, BOD_5 and COD to 86.81 %, 89.308 %, 83.17 %, and 75.4 % respectively at MOSP dose 1100 mg/l at time of sedimentation 45 min. Excessive coagulant dosage more than the optimum dosage can contaminate wastewater. Excess coagulant saturates the surface of colloids. The saturated coagulant stabilizes particles and creates a repulsive force between contaminants, preventing flocs formation [11].

Furthermore, the removal rate of turbidity, TSS, $BOD_{5,}$ and COD is 96.42 %, 98.92 %, 93.69 % and 89.28 % respectively, at MOSP dose of 720 mg/l at the time of sedimentation of 15 min.

The following equations illustrate the relationship between Dose and time of sedimentation that have been investigated and their impact on turbidity (Eq. 5), TSS (Eq. 6), BOD_5 (Eq. 7) and COD (Eq. 8).

$$\text{Turbidity removal \%} = 56.616 + 0.107884\ \text{dose} + 0.025109\ \text{time} - 0.000047\ \text{dose} * \text{time} - 0.000073\ \text{dose2} + 0.000523\ \text{time2} \quad \text{(Eq. 5)}$$

$$\text{TSS removal \%} = 64.5191 + 0.099536\ \text{dose} + 0.117284\ \text{time} - 0.000047\ \text{dose} * \text{time} - 0.000068\ \text{dose2} - 0.001171\ \text{time2} \quad \text{(Eq. 6)}$$

$$BOD_5\ \text{removal \%} = 58.0833 + 0.110323\ \text{dose} - 0.368913\ \text{time} - 0.000050\ \text{dose} * \text{time} - 0.000076\ \text{dose2} + 0.007297\ \text{time2} \quad \text{(Eq. 7)}$$

$$\text{COD removal \%} = 61.33545 + 0.085230\ \text{dose} - 0.135129\ \text{time} - 0.000033\ \text{dose} * \text{time} - 0.00006\ \text{dose2} + 0.003151\ \text{time2} \quad \text{(Eq. 8)}$$

The R-squared (measures the proportion of the total variation in the response variable that is explained by the model) for equations are 0.948, 0.840, 0.877, and 0.836 for turbidity, TSS, BOD_5 and COD removal respectively. However, adjusted R-squared (a modified version of R^2 that penalizes the addition of unnecessary predictors) are 0.921, 0.665, 0.726 and 0.636 for turbidity, TSS, BOD_5 and COD removal, respectively.

The indication of positive or negative effects is represented by the signs positive or negative. The coefficients for each of these factors represent their impact. The relation between the two factors and the quadric effects are illuminated by the double-factor coefficients [26].

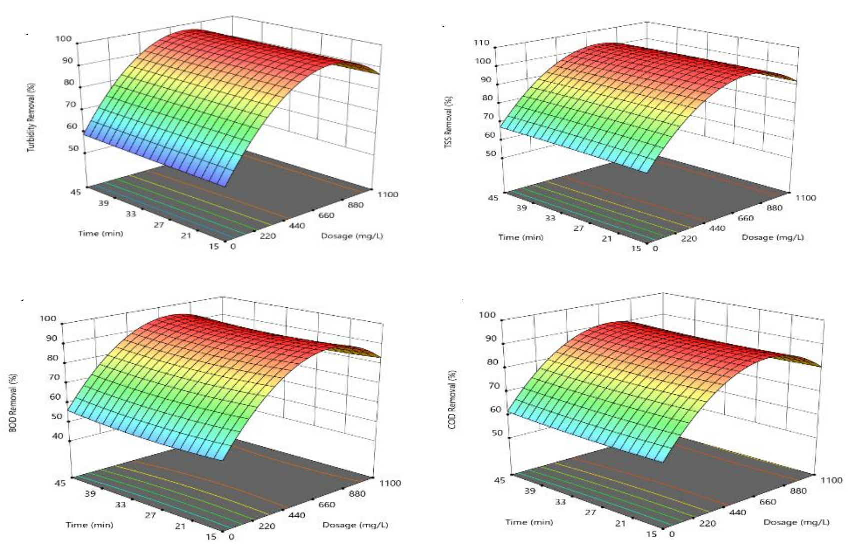

Fig. 3(a, b, c, and d): Relation between (MOSP) dosage and time of sedimentation which (a) 3D-Surface Plot for turbidity removal, (b) 3D-surface plot for TSS removal, (c) 3D-surface plot for BOD_5 removal, (d) 3D-surface plot for COD removal

Table 4: the effect of MOSP at different doses and different times of sedimentation on the turbidity, TSS, BOD_5 and COD removal.

Experimental	Time of sedimentation min	Coagulants dose mg/l	Turbidity removal %	TSS removal %	BOD_5 removal %	COD removal %
1	45	500	57.16	58.12	46.62	53.13
2	15	0	94.27	98.95	89.47	87.81
3	15	500	63.8	81.15	72.18	74.06
4	30	500	94.2	98.7	90.5	87.2
5	30	550	90.43	96.14	87.2	84.3
6	45	0	89.73	95.41	85.78	83
7	30	200	94.39	98.97	90	88.28
8	15	100	94.32	98.72	91.4	87.8
9	15	550	77.75	89.23	77.09	80.16
10	15	1000	89.48	97.43	78.5	81.06
11	45	100	91.41	96.69	88.07	85.23
12	15	1100	92.1	97.3	88.29	86.13
13	45	1000	94.28	98.58	92.35	87.25
14	45	1100	94.56	99.01	90.05	88.41
15	30	300	59.3	60.42	49.55	55.42
16	45	550	65.54	82.09	73.71	75.33
17	30	900	90.91	96.35	87.91	85.07
18	30	800	90.24	95.66	86.56	83.83
19	30	600	94.61	98.82	91.5	87.92

B. Effect of (MSP) Dose and Time of Sedimentation on The Turbidity, TSS, BOD5 and COD Removal

The effect of MSP dose and time of sedimentation on turbidity, TSS, BOD_5 and COD removal is shown as a 3D plot in Fig. 4 a, b, c and d. As shown in Fig. 4, the increase of MSP dose from 100 mg/l to 480 mg/l and the increase of time of sedimentation from 15 min to 45 min resulted in a significantly greater rate of pollution removal. The results are detailed in Table 5.

Fig. 4 a, b, c the turbidity, TSS, BOD_5 and COD removal rate respectively. At MSP dose of 480 mg/l and time of sedimentation of 45 min, the turbidity, TSS, BOD_5 and COD removal rate is 73.55 %, 62.57%, 59.87% and 51.52% respectively.

Furthermore, using MSP dose greater than 480 mg/l leads to a decrease in the removal rate of turbidity, TSS, BOD_5 and COD to 55.76 %, 53.23 %, 49.43 % and 38.86 % respectively at MSP dose 1100 mg/l at time of sedimentation 45min.While using MSP dose of 480 mg/l at the time of sedimentation of 15 min, the removal rate of turbidity, TSS, BOD_5 and COD is 72.71 %, 60.83 %, 58.51 % and 49.94 % respectively. The increasing of MSP dose leads to increasing in final BOD_5 and COD. These factors may be related to the coagulant's high charge density, which indicates lower dosages are sufficient for destabilizing suspended particles, while higher dosages generate interferences [28].

The following equations illustrate the relationship between dose and time of sedimentation that have been investigated and their impact on turbidity (Eq. 9), TSS (Eq. 10), BOD_5 (Eq. 11) and COD (Eq. 12).

*Turbidity removal % = 60.0697 + 0.051176 dose – 0.032593 time + 0.000016 dose * time – 0.000051 dose2 + 0.000884 time2* *(Eq. 9)*

*TSS removal % = 49.2449 + 0.031994 dose + 0.259308 time + 0.000043 dose * time – 0.000031 dose2 – 0.003698 time2* *(Eq. 10)*

*BOD_5 removal % = 45.08663 + 0.047048 dose + 0.000507 time + 0.00002 dose * time – 0.000041 dose2 + 0.00591 time2* *(Eq. 11)*

*COD removal % = 45.37362 + 0.018094 dose + 0.118077 time + 0.000022 dose * time – 0.000025 dose2 - 0.001269 time2* *(Eq. 12)*

The R-squared for equations are 0.8472, 0.5418, 0.4658, and 0.4938 for turbidity, TSS, BOD_5, and COD removal respectively. However, adjusted R-squared are 0.7422, 0.2569, 0.0926, and 0.1144 for turbidity, TSS, BOD_5, and COD removal respectively.

The indication of positive or negative effects is represented by the signs positive or negative. The coefficients for each of these factors represent their impact. The relation between the two factors and the quadric effects are illuminated by the double-factor coefficients [26].

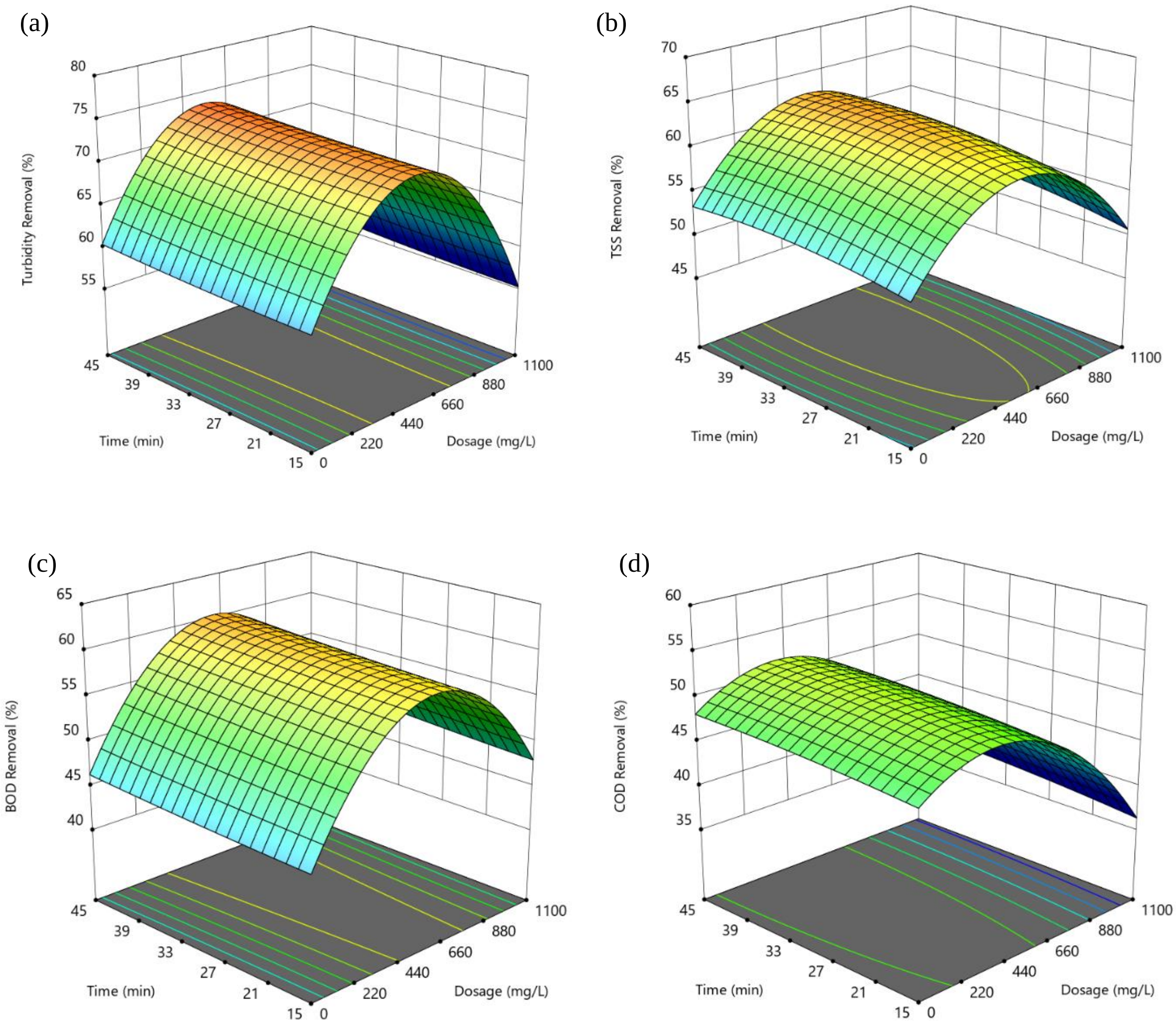

Fig. 4(a, b, c, and d): Relation between (MSP) dosage and time of sedimentation which (a) 3D-Surface Plot for turbidity removal, (b) 3D-surface plot for TSS removal, (c) 3D-surface plot for BOD_5 removal, (d) 3D-surface plot for COD removal

Table 5: the effect of MSP at different doses and different times of sedimentation on the turbidity, TSS, BOD_5 and COD removal.

Experimental	Time of sedimentation min	Coagulants dose mg/l	Turbidity removal %	TSS removal %	BOD_5 removal %	COD removal %
1	45	300	75.26	65.33	64.33	57.53
2	15	0	57.32	49.42	40.67	42.5
3	15	300	74.24	63.9	62.67	55.56
4	30	0	58.18	50.43	42.15	43.94
5	30	100	65.18	60.69	53.2	54.5
6	45	0	59.01	51.42	43.34	45.06
7	30	900	64.22	58.76	53.84	42.4
8	15	400	73.24	60.01	57.33	51.11

Experimental	Time of sedimentation min	Coagulants dose mg/l	Turbidity removal %	TSS removal %	BOD_5 removal %	COD removal %
9	15	800	66.19	56.44	53.72	41.61
10	15	1000	59.46	52.97	51.6	38.99
11	45	800	67.53	58.16	55.78	44.21
12	15	1100	56.75	52.48	49.47	38.8
13	45	900	64.93	59.59	54.77	43.55
14	45	1100	58.46	54.83	53.75	41.7
15	30	300	74.75	64.62	63.6	56.67
16	45	550	72.41	60.05	56.5	48.57
17	30	550	71.74	59.15	56.1	48.14
18	30	700	68.97	59.73	55.04	43.71
19	30	1100	57.61	53.43	50.73	39.35

C. Effect of (BPP) Dose and Time of sedimentation on the turbidity, TSS, BOD5 and COD removal

The effects of BPP dose and time of sedimentation on turbidity, TSS, BOD_5 and COD are presented as 3D plots in Fig. 5 (a, b, c, and d) that indicates the increase of the sedimentation time from 15 min to 45 min and the dose from 20 mg/l to 720 mg/l leading to a significantly greater rate of pollution removal. The results are detailed in Table 6.Fig. 5 (a, b, c, and d) show the turbidity, TSS, BOD_5 and COD removal rate respectively. At BPP dose of 105 mg/l and time of sedimentation of 45 min, the turbidity, TSS, BOD5 and COD removal rate is 66.98 %, 57.93%, 58.76% and 44.09% respectively.

However, its effectiveness gradually decreases when the BPP dose is increased to 105 mg/l or more. Using a BPP dose greater than 105 mg/l leads to a decrease in the removal rate of turbidity, TSS, BOD_5 and COD to 60.46 %, 54.85 %, 55.29 % and 39.17 % respectively at BPP dose of 220 mg/l at time of sedimentation of 45 min. Furthermore, the removal rate of turbidity, TSS, BOD_5 and COD is 63.38 %, 52.68 %, 54.71 % and 37.92 % respectively at a BPP dose of 105 mg/l at the time of sedimentation 15 min. A coagulant concentration higher than the optimum value might hinder the reaction between the coagulant and the particles in wastewater. This reduction indicates overdose causes colloidal particle destabilization and charge reversal. Hydrolyzation of coagulants in wastewater discharges cationic species that can be absorbed by negatively charged particles and neutralized. The mechanism of particle destabilization enables the flocculation process to occur, and coagulant overdose may interfere with this process [6].

The following equations illustrate the relationship between Dose and time of sedimentation that have been investigated and their impact on turbidity (Eq. 13), TSS (Eq. 14), BOD_5 (Eq. 15) and COD (Eq. 16).

*Turbidity removal % = 51.56 + 0.101052 dose + 0.542635 time – 0.000026 dose * time – 0.000482 dose2 + 0.000523 time2* *(Eq. 13)*

*TSS removal % = 33.2519 + 0.17314 dose + 0.648494 time – 0.000239 dose * time – 0.000582 dose2 – 0.007478 time2* *(Eq. 14)*

*BOD_5 removal % = 45.2351 + 0.118773 dose + 0.137049 time – 0.000028 dose * time – 0.000454 dose2 + 0.0000089 time2* *(Eq. 15)*

*COD removal % = 26.5973 + 0.05663 dose + 0.712532 time + 0.000115 dose * time – 0.000322 dose2 – 0.008644 time2* *(Eq. 16)*

The R-squared for equations are 0.8585, 0.7188, 0.4484 and 0.9593 for turbidity, TSS, BOD_5 and COD removal respectively. However, the Adjusted R-squared are 0.8229, 0.5827, 0.2737 and 0.9455 for turbidity, TSS, BOD_5 and COD removal respectively.

The indication of positive or negative effects is represented by the signs positive or negative. The coefficients for each of these factors represent their impact. The relation between the two factors and the quadric effects are illuminated by the double-factor coefficients[26].

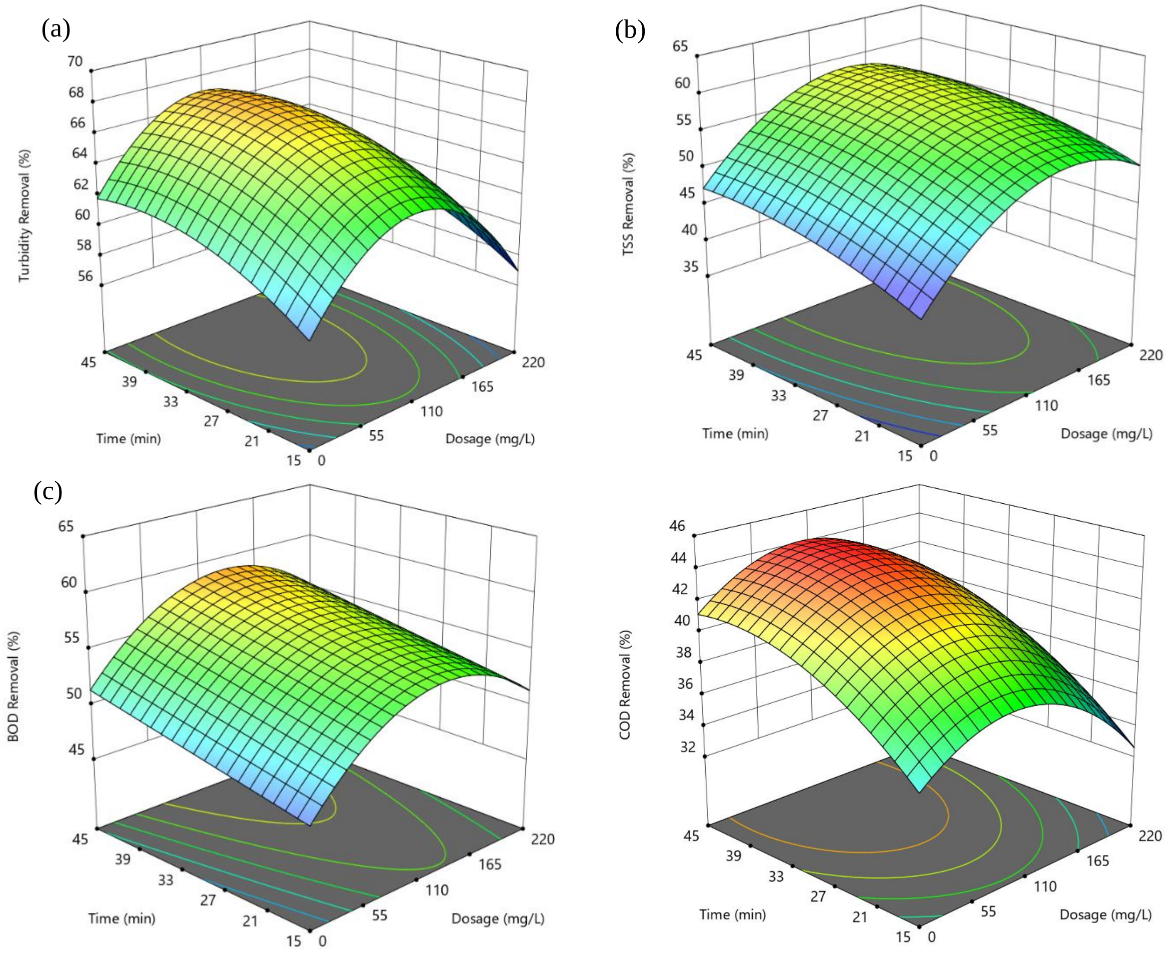

Fig. 5(a, b, c, and d): Relation between (BPP) dosage and time of sedimentation, a 3D-surface plot for turbidity removal – b 3D-surface plot for TSS removal – c 3D-surface plot for BOD_5 removal – d 3D-surface plot for COD removal

Table 6: the effect of BPP at different doses and different times of sedimentation on the turbidity, TSS, BOD_5 and COD removal.

Experimental	Time of sedimentation Min	Coagulants dose mg/l	Turbidity removal %	TSS removal %	BOD_5 removal %	COD removal %
1	15	80	62.44	49.09	52.25	37.9
2	15	160	61.38	55.52	55.9	36.63
3	45	100	66.47	55.74	54.3	43.95
4	30	60	64.94	51.97	56.88	42.07
5	15	0	58.25	43.35	46.54	35.53
6	30	20	63.84	45.39	46.88	40.97
7	30	140	69.32	64.37	61.31	44.23
8	15	40	61.82	46.22	54.61	37.19
9	45	160	65.96	60.22	60.04	42.58
10	30	0	61.19	48.03	50.31	40.09
11	45	40	65.04	51.89	58.87	43.09
12	30	180	62.98	57.47	55.74	39.9
13	30	100	65.61	54.61	53.13	42.51
14	45	220	61.06	54.05	55.25	39.53

Experimental	Time of sedimentation Min	Coagulants dose mg/l	Turbidity removal %	TSS removal %	BOD_5 removal %	COD removal %
15	30	220	60.06	52.87	54.1	37.98
16	15	220	57.02	48.63	50.61	32.27
17	15	180	60.16	53.64	52.37	35.34
18	45	200	61.65	56.29	55.89	40.23
19	45	0	57.61	49.33	51.55	41.59

IV. CONCLUSION

- The optimum operating conditions for (MOSP) at a dose of 720 mg/l and at 45 min time of sedimentation. However, The optimum operating conditions for (MSP) at a dose of 480 mg/l and at 45 min time of sedimentation. Furthermore, The optimum operating conditions for (BPP) at a dose of 105 mg/l and at 45 min time of sedimentation.
- The turbidity, TSS, BOD_5 and COD removal rate at optimum operating conditions is 97.1 %, 99.3%, 94.67%, and 85.1% respectively for (MOSP).
- The turbidity, TSS, BOD_5 and COD removal rate at optimum operating conditions is 73.5 %, 65.5 %, 59.8 %, and 51.5 % respectively for (MSP).
- The turbidity, TSS, BOD_5 and COD removal rate at optimum operating conditions is 66.9 %, 57.9 %, 58.75 %, and 44.1 % respectively for (BPP).
- The increase in MOSP, BPP, and MSP doses over the optimum dose led to a reduction in the efficiency of removal.

V. RECOMMENDATIONS

Using a pilot scale and evaluating the natural coagulants on the industrial wastewater.

Declaration

Conflict of interest

Conflict of interest: The authors declare that they have no conflict of interest

Data availability

This article includes all of the data analyzed during this research. The raw data that support the findings of this study are accessible upon request from the author.

Funding

This research did not obtain any specific funding from public, commercial, or non-profit organizations.

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