Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(1), 1316-1328 | ISSN:2251-6727

Studies on Removal of Soluble Phosphorous & Turbidity from Municipal Wastewater using Electrocoagulation

A. Saisailesh[1], S. Raj Kamal[2], M. Murali Naik[3], M. Kalyan Kumar[4]

[1,3,4.] Department of Chemical Engineering, JNTUA College of Engineering Ananthapuramu,

[2]Department of Civil Engineering, Anantha Lakshmi Institute of Technology and Sciences, Ananthapuramu.

[1,2,3.4] *Affiliated to JNTU Anantapur, Ananthapuramu, Andhra Pradesh, 515002, India*

(Received: 27 October 2023 Revised: 22 November Accepted: 26 December)

KEYWORDS

electrocoagul -ation, iron & aluminum electrodes, soluble phosphorous, turbidity, central composite design (CCD), response surface methodology (RSM).

ABSTRACT:

Enormous human activity, industrialization, and the use of excessive fertilisers are resulting in the discharge of nutrient-rich (N and P) wastewater into water bodies, leading to eutrophication, increasing the algal population, deteriorating the physico-chemical characteristics of the water, and inhibiting the growth of aquatic life. Eutrophication leads to a decrease in dissolved oxygen [DO] and increases the turbidity in water bodies, generating a toxic environment for aquatic life. The study aims to remove simultaneously phosphorous and turbidity from municipal wastewater using electrocoagulation. Soluble phosphorous is determined spectrophotometrically, and turbidity is found using a nephelometer. Synthetic wastewater was prepared and used for the optimisation studies. Operational parameters were optimised using response surface methodology. The application of electrocoagulation for the treatment of Ananthapuramu municipal wastewater under optimal conditions of an initial pH of 5.5, a voltage of 7.5 V, a runtime of 60 min, an inter-electrode distance of 3.5 cm, and an agitation speed of 350 rpm allowed for the removal of 76.65% phosphorous and 71.42% turbidity. The resultant treated wastewater conforms to the pollution norms, facilitating its reuse or release into natural water bodies.

1. Introduction

Each and every living thing depends on water to survive. It is unthinkable that life could exist without water. The current water sources, however, are unable to keep up with the increasing demand due to the significant increase in the world's population and the speed at which cities are being developed. The untreated direct discharge of domestic and industrial wastewater into earth's freshwater reservoirs poses a threat to their purity. Particularly domestic wastewater is full of organic pollutants [1], an essential component of living things' survival is phosphorus (P). This nutrient is mostly present in plants and animals as phosphate, where it is necessary for the synthesis of nucleotides and the synthesis of adenosine triphosphate. Phosphate is nevertheless a common fertilizer in farming and animal supplements. Farming areas immediately release excess P into water bodies, where P concentrations rise sharply. Therefore, limiting the amount of phosphorous released from industrial and municipal wastewater treatment facilities is essential to keeping surface waters from becoming eutrophic. Complex plant configurations, longer treatment times, and lower removal efficiency are all disadvantages for biological phosphorus removal processes. On the other hand, due to its affordability, simplicity, and adaptability, chemical precipitation with coagulants like calcium, aluminium, and iron salts is preferable. With >90% phosphorus removal efficiency at various process conditions, the electrocoagulation (EC) process, which uses sacrificial metal anodes to remove phosphorous from aqueous solutions, has garnered significant attention in recent research and development [2,3]. When compared to conventional methods, the electrocoagulation (EC) technique offers several advantages, including ease of use, simplicity, shorter retention times, no or minimal chemical addition, faster sedimentation of the electro generated flocs, reduced sludge production, and environmental compatibility [4].

Mechanism of phosphate removal with EC:

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JCHR (2024) 14(1), 1316-1328 | ISSN:2251-6727

During the electro dissolution of a sacrificial anode, typically composed of iron (Fe) or aluminium (Al), coagulants are produced in-situ. Hydrogen gas is released from the cathode while metal ions are generated at the anode. The hydrogen gas aids in the flocculated particles' removal from the water [5, 6].

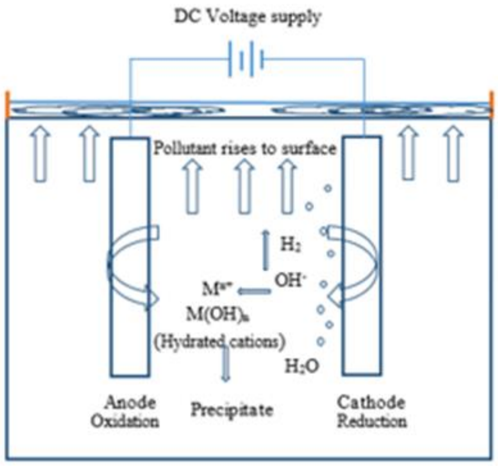

Fig.1. Mechanism of electrocoagulation

Al electrode:

Anode: $Al \rightarrow Al^{3+} + 3e^-$ (1)

Cathode: $3H_2O + 3e^- \rightarrow \frac{3}{2} H_2\,(g) + 3OH^-$ (2)

Fe electrode:

Anode: $Fe \rightarrow Fe^{2+} + 2e^-$ (3)

Cathode: $2H_2O + 2e^- \rightarrow H_2\,(g) + 2OH^-$ (4)

In the presence of water containing iron and aluminium, under low pH conditions (<6.5), $FePO_4(s)$ and $AlPO_4(s)$ compounds are formed. At higher pH levels (>6.5), iron and aluminium progressively transform into oxides and hydroxides. $FePO_4(s)$ displays minimal solubility within the pH range of 4.5-5.5, but its solubility rises as pH increases [5, 6].

$3Fe^{2+} + 2PO_4^{3-} \rightarrow Fe_3(PO_4)_2(s)$ (5)

Al or Fe^{+}+ PO $\rightarrow FePO_4(s)$ or $AlPO_4(s)$ (6)

$xFe^{+} + PO_4^{3-} + (3x-3)OH^- \rightarrow Fe_xPO_4(OH)_{3x-3}(s)$ (7)

$xA1^{3+} + PO_4^{3-} + (3x-3)\,OH^- \rightarrow Al_x\,PO_4(OH)_{3x-3}(s)$ (8)

2. Objectives

The objective of the work is to optimize the electrocoagulation (EC) process for maximum removal phosphorous and turbidity from synthetic wastewater modelled on municipal wastewater. Treatment of real wastewater from Ananthapuramu city located in the state of Andhra Pradesh, South India, by EC process at optimized process parameters was conducted to ascertain the suitability of the process and report observed removal of percentages of phosphorous and turbidity.

3. Methods and materials

3.1 Synthetic wastewater

Common chemicals are considered to simulate typical components found in municipal wastewater [7]. 100 mg of disodium hydrogen phosphate (Na_2HPO_4), 40 mg of ammonium chloride (NH_4Cl) and 20 mg of potassium chloride (KCl) are add to 2 L of distilled water for nutrients inclusion. For trace element addition 60 mg of calcium chloride ($CaCl_2$), 20 mg of magnesium sulphate ($MgSO_4$), 100 mg of sodium bicarbonate ($NaHCO_3$) and 40 mg of sodium sulphate (Na_2SO_4) are add to the solution. Clay is added to induce required turbidity. The solution is stirred well to disperse the particles in solution. The pH of the solution is adjusted between 7 and 7.5 using 0.1 M H_2SO_4 for decreasing pH and 0.1M NaOH for increasing pH.

3.2 Ananthapuramu city waste water sample

Ananthapuramu is a city located in the state of Andhra Pradesh, South India. The city with a population of around 4.86 lakhs lets its waste water into two natural drains "Maruvavanka" and "Nadimivanka". The waste water for EC treatment was sampled from Nadimivanka stream (Fig.2).

Fig.2. Nadimivanka (14.68408960 N and 77.58768850 E)

3.3 Experimental setup and procedure

The electrocoagulation unit consists of 2 L glass beaker. Aluminium and iron electrodes(150×50×2 mm) are used as anode and cathode respectively . The key operational parameters for the experiment are pH, voltage, run time, agitation speed, and inter-electrode

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distance. Each experimental run is conducted at room temperature, and before each run, electrodes are thoroughly cleaned with distilled water. Alligator clips are employed to link these electrodes to an external DC source, facilitating electrolysis. An external DC source, specifically a battery eliminator (with voltage levels ranging from 3-12 V), is utilized for this purpose. To ensure effective agitation of the solution during electrolysis, a magnetic stirring bar is introduced into the cell. During each experimental run, inter electrode distance, different values of voltage, time, and agitation speed are set, along with desired pH level for the wastewater sample. These parameters, both mechanical and wastewater related, are collectively termed as operational parameters of the electrocoagulation process (Fig.3).

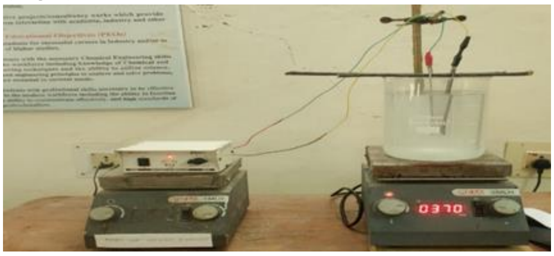

Fig.3. Electrocoagulation setup

3.4 Chemical and Analytical methods

3.4.1 pH control

The sample's pH level has a significant impact on how well phosphorus and turbidity are removed. 0.1M sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) are added to the sample to change its pH. The Systronics 361 digital pH meter is employed to measure pH of the samples.

3.4.2 Phosphorous

The chemical used for phosphate analysis is disodium hydrogen phosphate (Na_2HPO_4). The Visiscan spectrophotometer 167 is used for measuring the absorbance units of response samples. The absorbance of the solution measure at 715 nm [8].

3.4.3 Turbidity

The Systronics neohelometer 133 is a used for measuring the turbidity of samples.

3.5 Experimental design

A structured experimental approach using Design-Expert V13, a software by Stat Ease, is applied to assess and optimize various parameters based on Response Surface Methodology (RSM) outcomes. The key factors include pH, inter-electrode distance, voltage, run time, and agitation speed, each with five distinct levels (-1, -0.5, 0, 0.5, and +1). The experiment focused on evaluating 'P removal' and 'turbidity removal' as primary response variables. From the response value data, assessments are made and regression analysis is conducted. Analysis of variance (ANOVA) is used to identify the key factors significantly influencing the responses. Ultimately, a mathematical model is crafted using response surface methodology to encapsulate these findings [9]. The EC process is optimized using central composite design (CCD).

4. Results and discussion

4.1. Statistical analysis

Optimization of process and operating variables leads to an increase in process efficiency in the EC process. Following the characterization studies, the experimental data is processed using the Design Expert V13 software. Central composite design (CCD) and ANOVA analysis under RSM are performed for process development. Table 1 displays the outcomes derived from the RSM model, generated by software, consisting of two process responses namely phosphorous and turbidity removal. The anticipation of process performance was achieved by aligning experimental outcomes with empirical second-order polynomial models, as outlined in Table 2. In these models, the variables A, B, C, D and E represent, pH, voltage, runtime, agitation speed and inter electrode distance respectively. Positive coefficients within the models signify parameters with a favourable impact on the process responses, while negative coefficients denote an adverse effect. To assess the statistical significance and reliability of the experimental models, ANOVA was carried out (Table 3). In this analysis, variables and their interactions deemed insignificant were eliminated, retaining only those terms deemed significant in the final models. The "P" values, derived from ANOVA, were consistently below 0.05, indicating that the model terms were statistically significant at a confidence level of 95%.

Table 1 Central-composite design for the given factors and their corresponding removal efficiencies.

Std. Run No.	Variables					Responses	
	pH (A)	Voltage (V) (B)	Runtime (Min.) (C)	Agitation speed (RPM) (D)	Inter electrode Distance (cm) (E)	Phosphorous removal (%)	Turbidity removal (%)
1	**3**	**3**	**20**	**200**	**5**	**62.23***	57.71
2	8	3	20	200	2	65.43	66.31
3	3	12	20	200	2	90.11	58.67
4	8	12	20	200	5	77.40	70.40
5	3	3	100	200	2	76.54	65.11
6	8	3	100	200	5	66.15	72.51
7	3	12	100	200	5	72.29	62.14
8	8	12	100	200	2	74.66	86.25
9	**3**	**3**	**20**	**500**	**2**	70.89	**52.43***
10	8	3	20	500	5	67.77	71.45
11	3	12	20	500	5	68.87	63.63
12	**8**	**12**	**20**	**500**	**2**	75.65	**89.44****
13	3	3	100	500	5	65.43	56.87
14	8	3	100	500	2	74.33	72.72
15	**3**	**12**	**100**	**500**	**2**	**91.27****	65.11
16	8	12	100	500	5	66.67	81.50
17	3	7.5	60	350	3.5	72.20	60.87
18	8	7.5	60	350	3.5	70.20	80.33
19	5.5	3	60	350	3.5	69.73	66.80
20	5.5	12	60	350	3.5	83.53	76.00
21	5.5	7.5	20	350	3.5	76.50	71.24
22	5.5	7.5	100	350	3.5	78.34	73.46
23	5.5	7.5	60	200	3.5	70.76	73.99
25	5.5	7.5	60	350	2	75.53	76.95
26	5.5	7.5	60	350	5	65.32	68.49
27	5.5	7.5	60	350	3.5	73.65	70.29
28	5.5	7.5	60	350	3.5	76.78	71.34
29	5.5	7.5	60	350	3.5	75.36	71.98
30	5.5	7.5	60	350	3.5	76.54	69.34
31	5.5	7.5	60	350	3.5	74.33	72.93
32	5.5	7.5	60	350	3.5	75.19	73.78

* Lowest value. ** Highest value.

Table 2 RSM models obtained for the responses.

Response	Equation with significant term
Phosphorous removal (%)	74.2924 -1.75389 A + 4.55278 B + 0.601667 C -0.253333 D -4.57111 E -1.67187 AB -1.11687 AC + 0.343125 AD + 2.99437 AE -1.45437 BC -1.25437BD-1.30313BE + 1.25313CD -1.27813CE -0.920625DE -2.3304A^2 + 3.0996B^2 + 3.8896C^2 -3.0854D^2 -3.1054 E^2

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Turbidity removal (%)	$72.15+8.24A+3.96B+1.91C+0.5483D-1.57+1.70AB-0.0881AC+1.58AD-1.12AE-0.4031BC+1.90BD-1.49BE-2.10CD-0.781CE+0.4581CE+-1.96A^2-1.16B^2-0.2114C^2-0.6614D^2+0.1586E^2$

Table 3 ANOVA results for the obtained regression equations.

Response	S.D	Mean	C.V %	R^2	Adjusted R^2	Predicted R^2	Adequate precision	P value model	F value model
Phosphorous removal (%)	1.76	73.43	2.40	0.9742	0.9272	-0.1321	20.9089	< 0.0001	20.74
Turbidity removal (%)	2.26	70.00	3.22	0.9728	0.9235	-0.7657	20.598	< 0.0001	19.70

4.2 Phosphorous removal

The model's F-value of 20.74 (Table 4) signifies its overall significance, with only a 0.01% chance that such a large F-value could occur due to noise. A coefficient of determination (R^2) of 0.9742 (Table 3) indicates that 97.4% of sample variations in efficiency are explained by independent variables, highlighting a strong correlation between observed and predicted values in RSM. The remaining 2.6% of variation is unexplained. The adjusted R^2 value of 0.9272 aligns well with R^2, suggesting a well-fitted statistical model. The Lack of Fit F-value of 3.00 and a P-value of 0.1239 (Table 4) indicate not-significant, affirming the validity of the model. Lack of fit is statistically not-significant relative to pure error. Low coefficients of variation (CV) at 2.40% in (Table 3) demonstrate the model's dependability and reproducibility. The model's adequate precision ratio at 20.9089 surpasses the desirable threshold of 4, indicating that the signal-to-noise ratio is adequate for navigating the desired space [10].

4.3. Turbidity removal

The model's F-value of 19.70 (Table 5) suggests overall significance, with only a 0.01% chance that such a large "model F-value" could occur due to noise. The coefficient of determination R^2 at 0.9728 indicates that 97.28% of sample variations are efficiently explained by independent variables, leaving 2.72% unaccounted for by the model. This high R^2 value ensures a strong correlation between observed and predicted values, ensuring the success of RSM. The adjusted R^2 value of 0.9728 reasonably aligns with R^2, confirming the model's strength as a statistical model. The "lack of fit" F-value of 2.61 (Table 5) is not significant relative to pure error, confirming the model's validity, and the corresponding p-value of 0.1563 indicates non-significance for lack of fit. Low coefficient of variation (CV) values at 3.22% denote the model's dependability and reproducibility (Table 3). The model's adequate precision ratio at 20.5498 surpasses the desirable threshold of 4, indicating an adequate signal for navigating the desired space [10].

4.4 Process performance

Response Surface Methodology (RSM) is used to examine the effects of five different variables pH, voltage, runtime, agitation speed, in addition to the inter-electrode interactions. RSM approach clarifies the interactive effects of these independent parameters.

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Table 4 ANOVA table for phosphorous removal

S.No.	Source	Sum of Squares	df	Mean Square	F-value	P-value	Coefficient Estimate	
1	Model	1285.74	20	64.29	**20.74**	< 0.0001	74.29	Significant
2	A-pH	55.37	1	55.37	17.86	0.0014	-1.75	
3	B-voltage	73.10	1	373.10	120.34	< 0.0001	4.55	
4	C-time	6.52	1	6.52	2.10	0.1750	0.6017	
5	D-rpm	1.16	1	1.16	0.3726	0.5540	-0.2533	
6	E-distance	376.11	1	376.11	121.31	< 0.0001	-4.57	
7	AB	44.72	1	44.72	14.43	0.0030	-1.67	
8	AC	19.96	1	19.96	6.44	0.0276	-1.12	
9	AD	1.88	1	1.88	0.6076	0.4521	0.3431	
10	AE	143.46	1	143.46	46.27	< 0.0001	2.99	
11	BC	33.84	1	33.84	10.92	0.0070	-1.45	
12	BD	25.18	1	25.18	8.12	0.0158	-1.25	
13	BE	27.17	1	27.17	8.76	0.0130	-1.30	
14	CD	25.13	1	25.13	8.10	0.0159	1.25	
15	CE	26.14	1	26.14	8.43	0.0144	-1.28	
16	DE	13.56	1	13.56	4.37	0.0605	-0.9206	
17	A^2	13.36	1	13.36	4.31	0.0621	-2.33	
18	B^2	23.64	1	23.64	7.63	0.0185	3.10	
19	C^2	37.23	1	37.23	12.01	0.0053	3.89	
20	D^2	23.43	1	23.43	7.56	0.0189	-3.09	
21	E^2	23.73	1	23.73	7.65	0.0183	-3.11	
22	Residual	34.10	11	3.10				
23	Lack of Fit	26.70	6	4.45	**3.00**	**0.1239**		Not Significant

Table 5 ANOVA table for turbidity removal efficiency

S.No.	Source	Sum of squares	df	Mean square	F-value	P-value	Coefficient estimate	
1	Model	2004.02	20	100.20	**19.70**	< 0.0001	72.15	Significant
2	A-pH	1222.98	1	1222.9	240.47	< 0.0001	8.24	
3	B-voltage	281.87	1	281.87	55.42	< 0.0001	3.96	
4	C- time	65.70	1	65.70	12.92	0.0042	1.91	
5	D-rpm	5.41	1	5.41	1.06	0.3244	0.5483	
6	E-distance	44.46	1	44.46	8.74	0.0131	-1.57	
7	AB	46.14	1	46.14	9.07	0.0118	1.70	
8	AC	0.1243	1	0.1243	0.0244	0.8786	-0.0881	
9	AD	39.78	1	39.78	7.82	0.0174	1.58	
10	AE	20.00	1	20.00	3.93	0.0729	-1.12	
11	BC	2.60	1	2.60	0.5113	0.4895	-0.4031	
12	BD	57.72	1	57.72	11.35	0.0063	1.90	
13	BE	35.31	1	35.31	6.94	0.0232	-1.49	
14	CD	70.85	1	70.85	13.93	0.0033	-2.10	
15	CE	9.78	1	9.78	1.92	0.1930	-0.7891	

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16	DE	3.36	1	3.36	0.6603	0.4337	0.4581	
17	A^2	9.47	1	9.47	1.86	0.1997	-1.96	
18	B^2	3.32	1	3.32	0.6527	0.4363	-1.16	
19	C^2	0.1100	1	0.1100	0.0216	0.8857	-0.2114	
20	D^2	1.08	1	1.08	0.2117	0.6544	-0.6614	
21	E^2	0.0619	1	0.0619	0.0122	0.9141	0.1586	
22	Residual	55.94	11	5.09				
23	Lack of Fit	42.39	6	7.06	**2.61**	**0.1563**		Not Significant

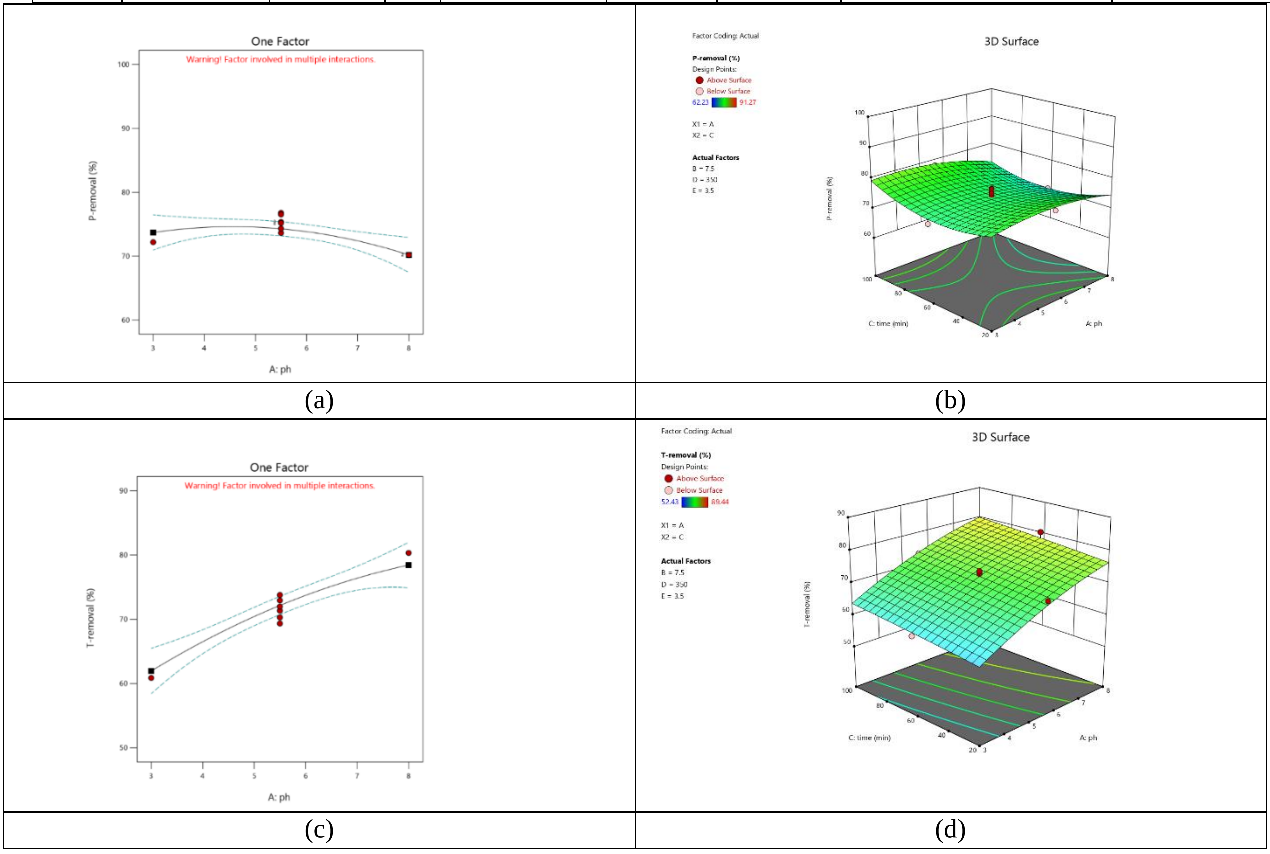

Fig.4. Response surface (RS) plots for effect of pH on phosphorous removal % (a, b), turbidity removal % (c, d)

4.4.1 Effect of pH

The electrolyte's initial pH (pH_i) is a crucial factor that impacts the effectiveness of the electrochemical process [2, 3,]. The RS plot indicating the highest phosphorous removal is identified when the pH falls within the range of 3 to 5, with a corresponding runtime of approximately 100 minutes (Fig.2b). In the electrocoagulation process, if the wastewater pH is below 7, it tends to increase afterward, while an initial pH above 8 results in a decrease after electrocoagulation. This observation confirms the pH buffering nature of the electrocoagulation process. The removal efficiency of phosphorous exhibits an ascending curve when the pH is below 5.5, reaching its maximum 74.43% at pH 5.5 (Fig. 2a). Subsequently, the efficiency decreases for pH values greater than 7, with the lowest recorded at pH 8, i.e., 70.28%. The maximum turbidity removal is observed when pH ranging 7 to 8, runtime is ranging around 60 to 100 min (Fig.2d). The turbidity removal efficiency follows an ascending trend from lower to higher pH values. At pH 3, the lowest turbidity removal efficiency is recorded as 60.87%, while at pH 8, the removal efficiency is 80.33%. (Fig.2c).

4.4.2. Effect of voltage

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The key operational factor in the EC process is the applied voltage. Variating the applied voltage value allows one to examine how the voltage affects removal efficiency (3–12 V). Achieving the ideal applied voltage leads to a satisfactory and productive rate of pollutant removal. Removal efficiency does not significantly change above the ideal applied voltage, but it does increase operating costs [11]. The RS plot indicating the highest phosphorous removal efficiency is identified when the voltage is 10 to 12 V, with an EC time 60 to 100 min (Fig. 3b). At a cell voltage of 3.0 V, phosphorous removal 69.73 %. These values increase to 83.53 % at a cell voltage of 12 V (Fig.3a.). The optimal cell voltage for phosphorous removal is determined to be 7.5 V. The peak efficiency for turbidity removal is evident in the RS plot when the values for time and voltage fall within the range of 45 to 50 minutes and 7.0 to 7.5 V, respectively (Fig.3d). As cell voltage is increased from 3 V to 12 V, turbidity removal increased from 68.54 % to 76 % (Fig.3c). The optimal cell voltage for turbidity removal, is found to be 7.5 V, with a removal efficiency of 71.98%.

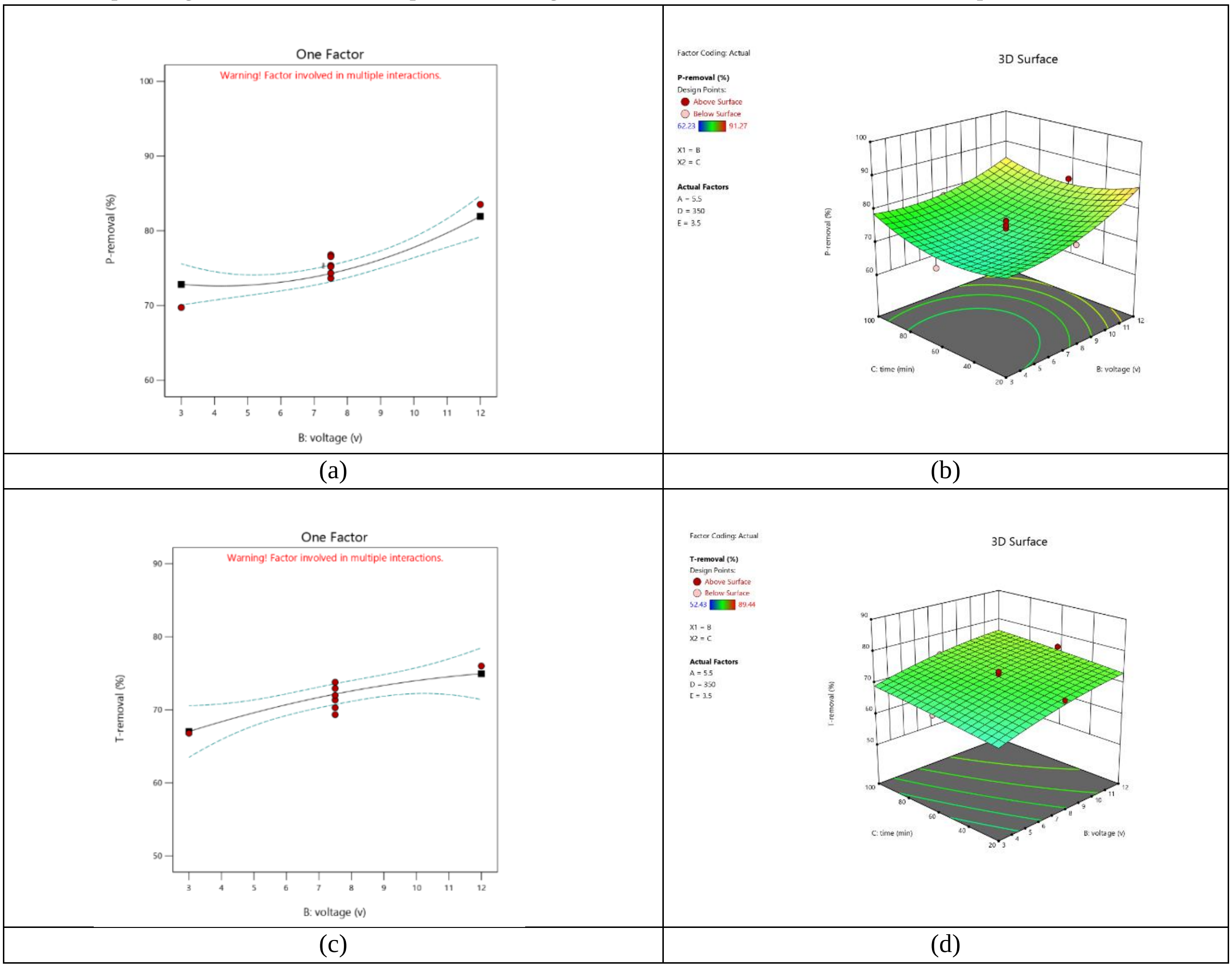

Fig.5. RS plots for effect of voltage on phosphorous removal % (a, b), turbidity removal % (c, d).

4.4.3. Effect of runtime

The efficiency of removal is maximized and eventually brought to a constant rate by lengthening the runtime. With an increase in runtime, more metal hydroxides are produced [12]. The RS plot that displays the maximum phosphorus removal efficiency can be found when the distance is between 2 and 3 cm and the EC time is between 60 and 100 minutes. (Fig.4b). RS plot that displays the maximum phosphorus removal efficiency is found when the distance is between 2 and 3 cm and the EC time between 60 and 100 minutes. (Fig.4b). The

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generated curve shows that as runtime increases, the phosphorus removal increase (Fig. 4a). After 20 minutes, the phosphorus is 76.5%. During the 60 minutes runtime, the phosphorus level is mildly decreased by 74.33%. During the 100-minute maximum runtime, the phosphorus removal is found to be 78.34%. The optimal turbidity removal RS plot is identified when the run time ranges from 60 to 100 minutes, and the agitation speed is between 200 and 350 rpm (Fig.4d). The turbidity removal after 20 minutes is 71.24%. The removal of turbidity increased to 72% in the course of 60 minutes runtime. Removal increased to 73.46 % by the end of 100 minutes runtime (Fig. 4c).

4.4.4 Effect of agitation speed

Agitation speed is an important operational parameter that greatly affects the EC process performance [13]. The RS plot that represents the maximum efficiency in removing phosphorus is found when

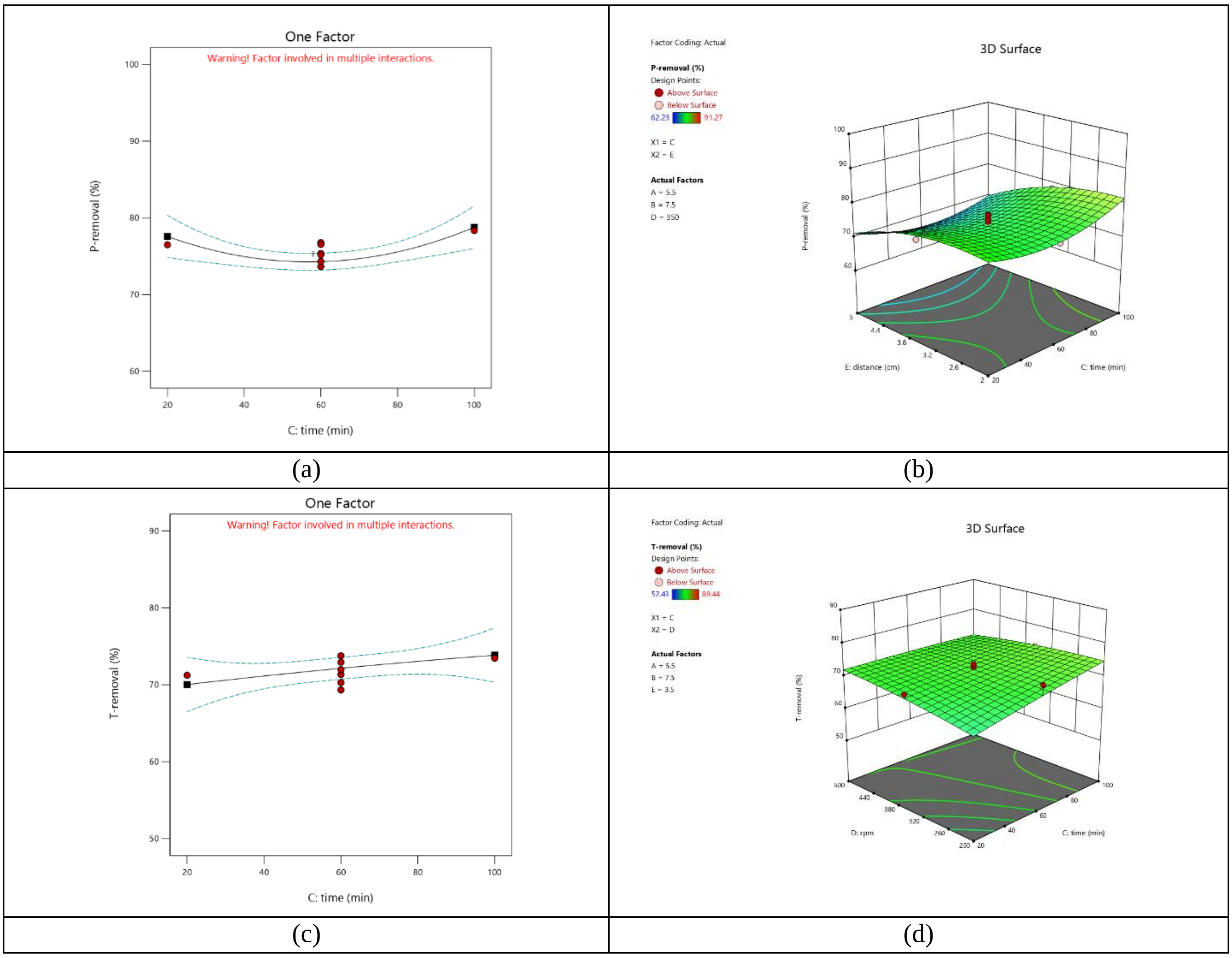

Fig.6. RS plots for effect of run time on phosphorous removal % (a, b), turbidity removal % (c, d).

the distance is between 2 and 3 cm, and the agitation speed is between 250 and 400 rpm (Fig.5b). The RS plots reveal the effect of agitation speed on the removal of phosphorus. Phosphorus removal is 70.76% at 200 rpm stirring (Fig.5a). The maximum phosphorus removal is 74.33% at 350 rpm and at 500 rpm, it is 70.13%. Beyond 350 rpm the rate of phosphorus removal gradually declined. The optimal range for maximizing turbidity removal is identified between agitation speed 200 to 350 rpm, inter electrode distance 2 to 3.5 cm (Fig. 5d). The RS plots c & d evaluate how agitation speed affects the removal of turbidity. At 200 rpm turbidity removal peaks at 73.99%. As speed of agitation is increased further, the removal of turbidity deceased continuously to reach 69.81% at 500 rpm.

4.4.5 Effect of inter electrode distance

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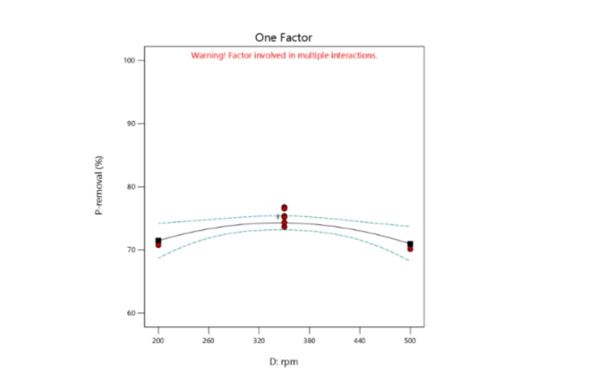
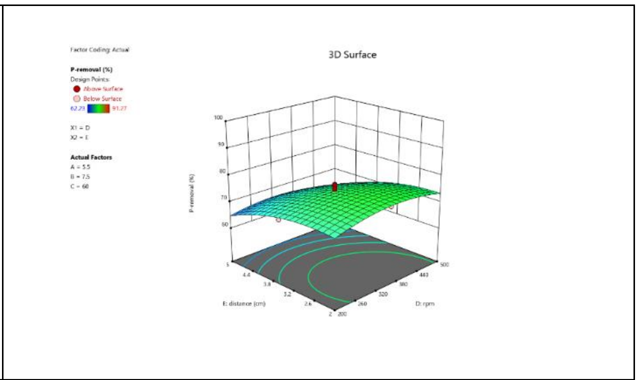
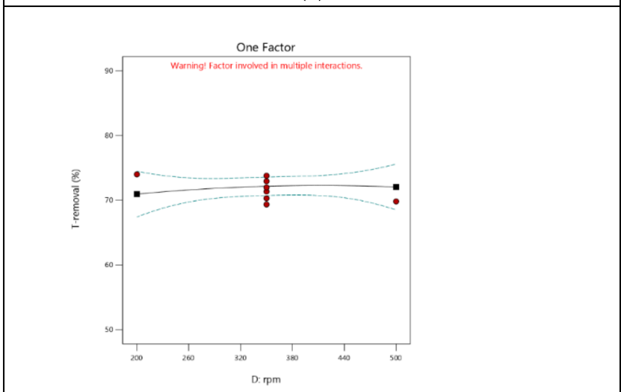
The effectiveness of the electrocoagulation process is significantly influenced by the distance between electrodes. This distance has a direct effect on the distribution of the electric field between the electrodes, [14]. The 3D plot that displays the maximum phosphorus removal efficiency can be found when the distance is between 2 and 3 cm and the EC time is between 60 and 100 minutes. (Fig.6b). The optimal range for maximizing turbidity removal is identified between EC time 60 to 100 min, inter electrode distance 2 to 3.5 cm (Fig.6d). The removal efficiencies of phosphorous and turbidity at a distance of 2 cm are 74.59% and 76.95%, respectively. The removal of turbidity dropped to 72.9% and the phosphorous efficiency marginally increased to 75.81% at a distance of 2.8 cm. At a distance of 5 cm, the removal efficiencies of phosphorous and turbidity are 63.32% and 68.49%, respectively (Figs.6a and 6c).



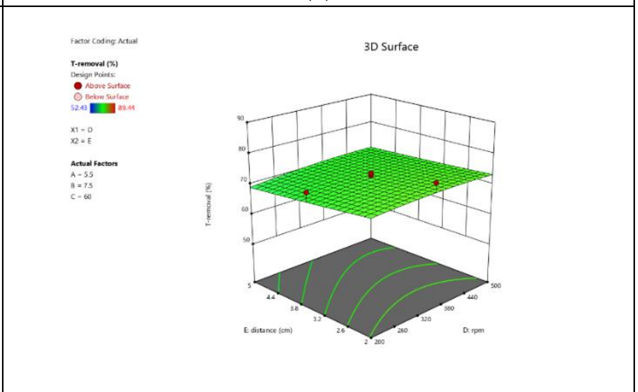
(a)



(b)

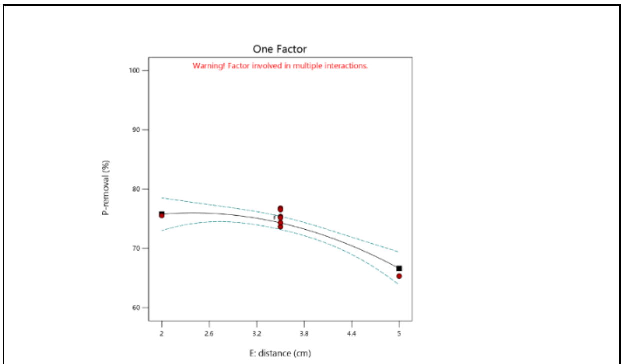


(c)

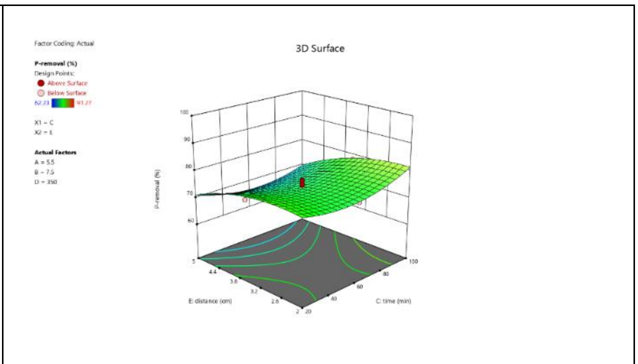


(d)

Fig.7. RS plots for effect of agitation speed on phosphorous removal % (a, b), turbidity removal % (c, d).



(a)



(b)

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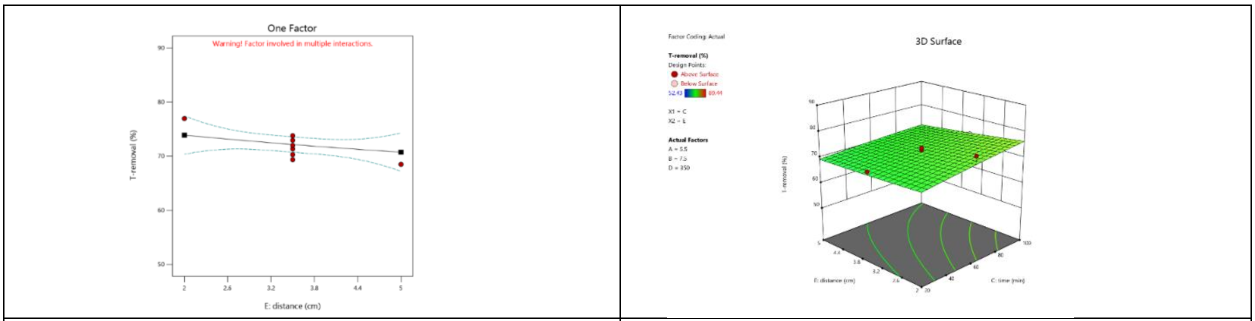
JCHR (2024) 14(1), 1316-1328 | ISSN:2251-6727



(c) (d)

Fig.8. RS plots for effect of inter electrode distance on phosphorous removal % (a, b), turbidity removal % (c, d).

4.5 Energy consumption of EC process

Voltage and run time have a significant impact on energy consumption. 3.18 KWh/m^3 is the energy consumption value for the optimized experimental condition. If the energy consumption is low, the operating cost will be economical (Table 6).

Table 6 Electrical energy consumption in KWh/m^3 at the optimized experimental conditions.

Std. Run No.	Voltage (V)	Current (A)	Runtime (min)	Treated volume (m^3)	Energy consumption (KWh/m^3)
1	7.5	0.85	60	0.002	3.18

4.6 Process optimization

The process optimization is determined during post-analysis. In the post-analysis, the optimized factors are identified (Table 7), and these factors are then tested in two trial runs to find response data (Table 8).

Table 7 Optimization factors by RSM

pH	Voltage (V)	Time (min)	Agitation speed (rpm)	Inter electrode distance (cm)
5.5	7.5	60	350	3.5

4.7. Validation and verification of predictive model

Validation and verification are required to ensure the model equation's reliability. Optimal values for the independent variables are arrived at after the model has been optimized. The predicted optimal response values are generated by entering the target responses. Maximum efficiency is required when setting response values. By running the experimental runs using the model-generated operational settings, the predicted phosphorous and turbidity removal efficiencies are confirmed and validated. It is found that the actual or experimental response values and the predicted response values for the specified operational parameters agree fairly well. The derived regression model's suitability in representing the anticipated optimization was validated by these results (Table 8).

4.8 Treatment of urban wastewater from Nadimivanka an open channel of Ananthapuramu city in Andhra Pradesh, South India.

The electrocoagulation process was at conducted the optimized process conditions. The phosphorous decreased from initial concentration of 23 mg/l to 5.3 mg/l with 76.65% removal. The turbidity decreased from 98 NTU to 28 NTU with 71.42% removal.

Table 8 Predicted (P) and observed (O) experimental values of phosphorous and turbidity removal

S.No.	pH	Voltage (V)	Time (min)	Agitation speed (rpm)	Inter electrode Distance (cm)	Phosphorous removal % (P)	Phosphorous removal % (O)	Turbidity removal % (P)	Turbidity removal % (O)
1	5.5	7.5	60	350	3.5	74.29	72.89	72.15	71.24
2	5.5	7.5	60	350	3.5	74.29	75.7	72.15	70.29

5. Conclusion

A batch electrocoagulation (EC) cell was employed for treatment of municipal wastewater. Central composite design with response surface methodology (RSM) was applied to find the optimal process conditions. ANOVA results for the second order polynomial models derived from the EC process indicated that these models are able to predict the responses with a good correlation between empiric and predicted data. The initial pH, voltage, runtime and inter electrode distance are major factors affecting treatment of wastewater using EC cell. Application of optimized process parameters pH 5.5, voltage 7.5 V, runtime 60 min, inter electrode distance 3.5 cm and agitation speed 350 rpm for Ananthapuramu municipal wastewater removed 76.65% of phosphorous and 71.42% of turbidity. The treated wastewater conforms to the CPCB norms making it suitable for release into natural water bodies.

Acknowledgment

The authors would like to acknowledge JNT University Anantapur, Ananthapuramu, Andhra Pradesh, India for the financial support provided for this research work under the Research Seed Grant (RSG) scheme.

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