Removal of phosphorous from sewage treatment plant by electrocoagulation

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Abstract*—Phosphorus removal from wastewater is a critical environmental concern due to its role in eutrophication. Electrocoagulation, an electrochemical water treatment method, has gained attention for its efficiency in removing phosphorus contaminants. This abstract presents an overview of the electrocoagulation process and its effectiveness in phosphorus removal. The electrocoagulation process involves the use of sacrificial electrodes to generate coagulating agents, primarily metal hydroxides, that aid in the precipitation and subsequent removal of phosphorus species. The mechanism involves destabilization of phosphorus particles through electrochemical reactions, forming flocs that are easily separated from the water. Various parameters influencing electrocoagulation's efficiency, such as pH, current density, electrode material, and electrolyte concentration, are discussed in this abstract. Optimization of these parameters is crucial for enhancing phosphorus removal efficiency while minimizing energy consumption and operational costs .Furthermore, the abstract highlights the advantages of electrocoagulation, such as its adaptability to different water qualities, relatively low sludge production, and potential for automation and integration into existing treatment processes. In conclusion, electrocoagulation exhibits significant promise as a sustainable and cost-effective method for phosphorus removal from wastewater. Continued research and technological advancements in this field hold the potential to address environmental concerns associated with phosphorus pollution effectively.

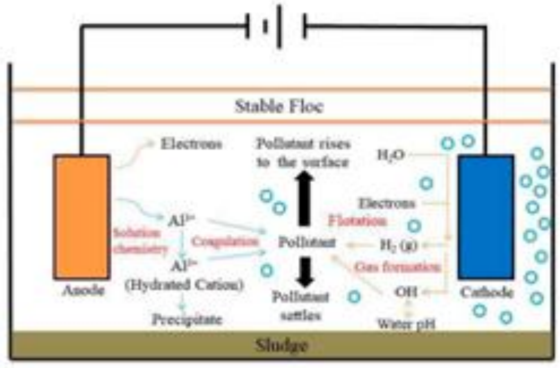
Keywords*— *Aluminium, Electrocoagulation, Eutrophication, Phosphate, Stainless steel

I. INTRODUCTION

Environmental contamination caused by domestic, municipal and industrial wastewater has become a serious environmental problem which has harmful consequences on the public health. The effluent from these industries is often responsible for severe pollution and contamination of ground water, rivers and lakes in the surrounding area (Heffron *et al.*, 2015). Phosphorus (P) is an essential element for industrial and agricultural products and found commonly in groundwater, domestic and industrial waste water (Zelmanov and Semiat., 2014). Phosphate pollution is a wide spread and challenging environmental problem because the presence of nutrients, especially nitrogen and phosphorus in wastewater effluents cause the anthropogenic phosphorus (not nitrogen) addition in milligrams per liter level to trigger algal growth. As a result, phosphorus removal to lowest level has become increasingly important. Discharge of P into the water bodies also results with the decrease of dissolved oxygen (DO), water quality deterioration, biodiversity reduction and fish death. P removal from wastewater is a complex process due to differences in its forms and in the composition of wastewater. The usual forms of P found in wastewater include orthophosphate, polyphosphate and organic phosphate. Municipal wastewater may contain 5-20 mg/L of TP. The maximum amount of P recommended for effluent discharge has been limited to 1 mg/L

II. ELECTROCOAGULATION

EC is a technology in which the coagulant is generated in situ by oxidation of a metal anode material when applying electrical current. When direct current is applied to water through a pair of electrodes, the water molecules are broken down into hydrogen and oxygen gas. The reaction is observed through the hydrogen bubbles that evolve from the cathode and oxygen bubbles that originate from the anode. EC has occurred in three steps. In first step, coagulant has formed because of oxidation of anode. In second step, pollutants have destabilized. In last step, destabilized matters have united..



III. METHODOLOGY

The methodology for the experiment involves several steps. Initially, a sample is collected from the Karaikudi Rastha Sewage Treatment Plant, specifically from the secondary clarifier. The collected wastewater is characterized by measuring parameters such as pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), phosphate levels, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and electrical conductivity.A batch-scale reactor setup with a 1-liter capacity and a working volume of 750 mL is used for the experiment. The anode is made of aluminum, the cathode of stainless steel, and sodium chloride (NaCl) serves as the electrolyte. The experiment then proceeds to optimize various parameters, including current density, electrolyte concentration, and electrolysis time.Finally, the treated effluent is characterized to assess the effectiveness of the treatment process. The entire process flow is detailed in the provided flowchart, illustrating the experimental methodology.

A. Characterisation methods

The samples collected from the proposed conventional sewage treatment plant (STP) will be subjected to initial characterization for parameters which will be determined according to Standard Methods for the Examination of Water and Wastewater (APHA 2017). The parameters and standard methods used to characterize the sample are summarized in the table below.

PARAMETERS	TEST METHODS	METHODS/ EQUIPMENTS
pH	4500-HB	pHmeter
Electricalconductivity	IS3025 (Part14)	Conductivitymeter
Chlorides	4500-Cl⁻B	Argentometric method
Phosphate	4500-PO_4^{2-}D	Stannouschloridemethod
TSS	2520 G	Gravimetricmethod
TDS	2540 C	Gravimetricmethod

B. Discharge standards

Sl. No	PARAMETERS	STANDARDS (except pH all values are in mg/L)			
		Inland surface water	Public sewers	Land of irrigation	Marine/ coastal areas
1.	pH	5.5-9	5.5-9	5.5-9	5.5-9
2.	Suspended solids	100	600	200	100
3.	BOD5 @ 27 ° C	30	350	100	100
4.	COD	250	-	-	250
5.	Dissolved phosphate as P	5	-	-	-

C. Experimental Configuration

A glass beaker with a working volume of 750 ml will be used as a batch scale reactor. The aluminum electrode and stainless steel of size 50 mm × 100 mm each were used for the anode and cathode respectively. The electrodes were held 2.5 cm apart with an electrode effective area, 30 cm^2, submerged in the solution held in 1 L container. The schematic diagram of EC unit is shown in the fig.1

Fig 1 – Electrocoagulation reactor setup

D. Operational Parameters

1)Effect of supporting electrolyte
2)Effect on current density
3)Effect on reaction time

IV. RESULTS AND DISCUSSIONS

A. CHARACTERISTICS OF WASTEWATER

The secondary treated wastewater collected from the Karaikudi Rastha sewage treatment plant for which the initial characteristics are carried out and their corresponding values are tabulated in the Table 3 below

Table 3 – Influent characteristics after secondary clarifier

SI.No	Parameters	Values
1.	pH	7.31
2.	Electricalconductivity (mS/cm)	4.25
3.	Chlorides	280
4.	Phosphorus	11.2
5.	TSS	25
6.	TDS	360
7.	COD	90
8.	BOD5@ 27 ° C	21

B. CHARACTERISATION OFWASTEWATER

Initial P concentration - (17 mg/L). Generally the P concentration in the sewage treatment plant varies from 5 to 20 mg/l. So the initial P concentration of the secondary treated sample collected from the STP was varied by adding potassium di-hydrogen orthophosphate to vary the initial P concentration to 17 mg/L, 11mg/L and 5mg/L to carry out the EC process and the operational parameter initially varied is the current. The current varied is from 0.25A and 0.50A with the corresponding current density of 8.33 mA/cm^2, 16.67 mA/cm^2 and 25 mA/cm^2 and after the reaction time the corresponding absorbance are noted and tabulated in Table 4, 5, 6 respectively.

Table 4 – Effect of current on phosphorousremoval (I=0.25A). Electrolyte used – NaCl (2.5, 5, 7.5 mM) ABS – Absorbance @ 660nm

TIME (MINUTES)	2.5 mM		5 mM		7.5 mM	
	ABS	%	ABS	%	ABS	%
0	0.660	0	0.654	0	0.637	0
10	0.621	6	0.591	10	0.560	12
20	0.532	19	0.422	35	0.495	22
30	0.438	34	0.240	63	0.235	63
40	0.279	58	0.139	79	0.107	83
50	0.176	73	0.082	87	0.075	88
60	0.117	82	0.064	90	0.047	93
70	0.079	88	0.041	94	0.032	95
80	0.037	94	0.036	95	0.028	96
90	0.028	96	0.030	96	0.024	96

Table 5– Effect of current on phosphorous removal (I=0. 5A)

Electrolyte used – NaCl (2.5, 5, 7.5 mM)
ABS – Absorbance @ 660nm

TIME (MINUTES)	2.5 mM		5 mM		7.5 mM	
	ABS	%	ABS	%	ABS	%
0	0.634	0	0.627	0	0.634	0
10	0.451	29	0.429	32	0.307	52
20	0.391	38	0.283	55	0.168	74
30	0.304	52	0.116	81	0.067	88
40	0.174	73	0.040	94	0.035	94
50	0.078	88	0.031	95	0.029	95
60	0.059	91	0.027	96	0.027	96
70	0.029	95	0.025	96	0.023	96
80	0.021	97	0.022	97	0.019	97
90	0.018	97	0.019	97	0.016	98

The absorbance values for different initial P concentration are tabulated and their corresponding graphs are plotted as shown in the Fig 2, and 3.

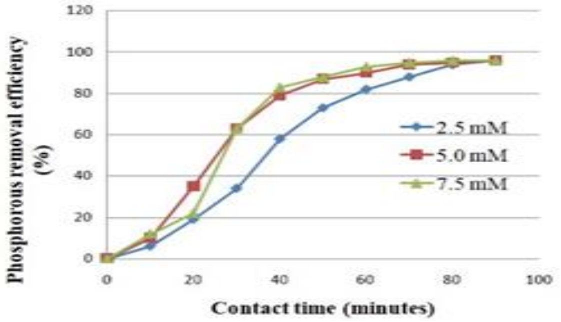


Fig 2 – Effect of 0.25A current on 17 mg/L of initial P concentration

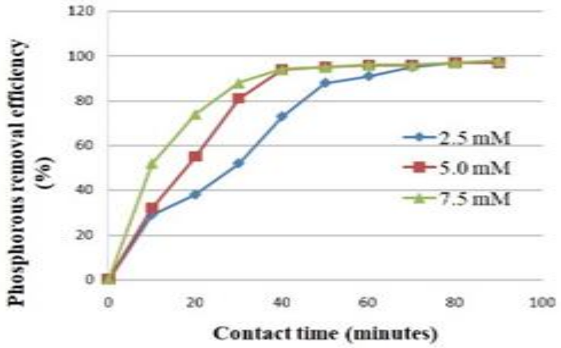


Fig 3 – Effect of 0.5A current on 17 mg/L of initial P concentration

From the above graphs it is observed that the behaviour of a phosphorus removal during the initial stages follow a linear increase this occurs when the treatment conditions are favourable and the reactions between the treatment agents i.e., the electrode-generated species in EC process and phosphorus compounds are efficient and well controlled. As the treatment progresses, several factors like competing reactions, particle agglomeration, reactor conditions can lead to fluctuating trend in P removal. Understanding these factors is important for optimizing treatment design and operational strategies. It is observed from the graph that >90% removal efficiency was achieved at 40 min in 0.5A while reducing the current to 0.25A, >90% removal was achieved in 60 min. As the current increases the removal efficiency increases with decrease in time.

Initial P concentration - (11 mg/L)

The initial P concentration for the secondary treated wastewater was varied to 11mg/L by adding potassium di-hydrogen orthophosphate and the operational parameter varied is the current from 0.25A .and.0.5A and the corresponding phosphorous absorbance at different time intervals are given in Table 6, 7respectively.

Table 6– Effect of current on phosphorous removal (I=0.25A)

Electrolyte used – NaCl (2.5, 5, 7.5 mM) ABS – Absorbance @ 660nm

TIME (MINUTES)	2.5 mM		5 mM		7.5 mM	
	ABS	%	ABS	%	ABS	%
0	0.415	0	0.417	0	0.409	0
10	0.395	5	0.350	16	0.310	24
20	0.283	32	0.276	34	0.230	44
30	0.179	57	0.162	61	0.155	62
40	0.115	73	0.111	74	0.106	74
50	0.090	78	0.086	80	0.079	81
60	0.075	82	0.073	82	0.065	84
70	0.066	85	0.061	85	0.055	87
80	0.045	90	0.040	90	0.035	92
90	0.036	91	0.029	93	0.020	95

Table 7 – Effect of current on phosphorous removal (I=0.5A)

Electrolyte used – NaCl (2.5, 5, 7.5 mM)

ABS – Absorbance @ 660nm

TIME (MINUTES)	2.5 mM		5 mM		7.5 mM	
	ABS	%	ABS	%	ABS	%
0	0.432	0	0.415	0	0.422	0
10	0.361	16	0.342	18	0.301	29
20	0.279	35	0.265	36	0.228	46
30	0.154	64	0.138	67	0.113	73
40	0.085	80	0.062	85	0.056	87
50	0.036	92	0.034	92	0.032	92
60	0.033	92	0.030	93	0.028	93
70	0.031	93	0.026	94	0.021	95
80	0.026	94	0.025	94	0.015	96
90	0.024	94	0.023	95	0.014	97

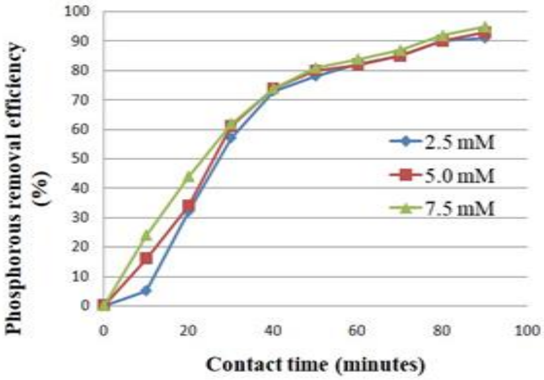


Fig 4– Effect of 0.25A current on 11 mg/L of initial P concentration

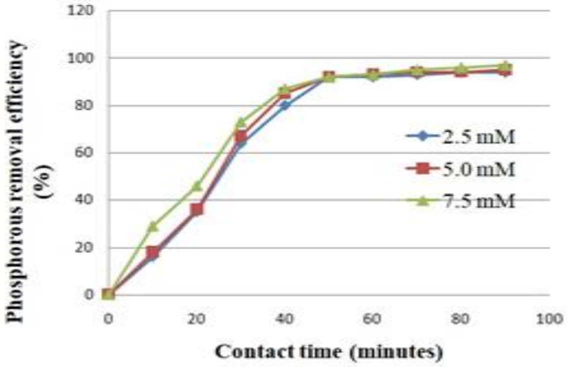


Fig 5 – Effect of 0.5A current on 11 mg/L of initial P concentration

Initial P concentration - (5 mg/L)

The initial P concentration for the secondary clarified water was varied to 5mg/L by adding potassium di-hydrogen orthophosphate and varying the current from 0.25A and 0.50A and the corresponding phosphorous absorbance at different time intervals are given in Table 8 and 9.

Table 8 – Effect of current on phosphorous removal (I=0.25A)

Electrolyte used – NaCl (2.5, 5, 7.5 mM) ABS – Absorbance @ 660nm

TIME(MINUTES)	2.5 mM		5 mM		7.5 mM	
	ABS	%	ABS	%	ABS	%
0	0.182	0	0.185	0	0.191	0
10	0.156	14	0.150	19	0.099	48
20	0.091	50	0.084	55	0.051	73
30	0.072	60	0.066	64	0.038	80
40	0.053	71	0.045	76	0.036	81
50	0.041	77	0.039	79	0.030	85
60	0.034	81	0.031	84	0.025	87
70	0.029	84	0.028	85	0.020	89
80	0.024	87	0.025	87	0.019	91
90	0.021	89	0.022	91	0.019	91

Table 9 – Effect of current on phosphorous removal (I=0.5A)

Electrolyte used – NaCl (2.5,5,7.5 mM) ABS – Absorbance @ 660nm

TIME (MINUTES)	2.5 mM		5 mM		7.5 mM	
	ABS	%	ABS	%	ABS	%
0	0.187	0	0.191	0	0.182	0
10	0.113	40	0.128	33	0.081	55
20	0.080	57	0.077	60	0.049	73
30	0.056	70	0.033	83	0.028	85
40	0.043	77	0.031	84	0.026	86
50	0.036	81	0.029	85	0.024	87
60	0.033	82	0.024	87	0.022	88
70	0.029	85	0.020	90	0.022	88
80	0.026	86	0.019	90	0.018	91
90	0.022	88	0.017	91	0.018	91

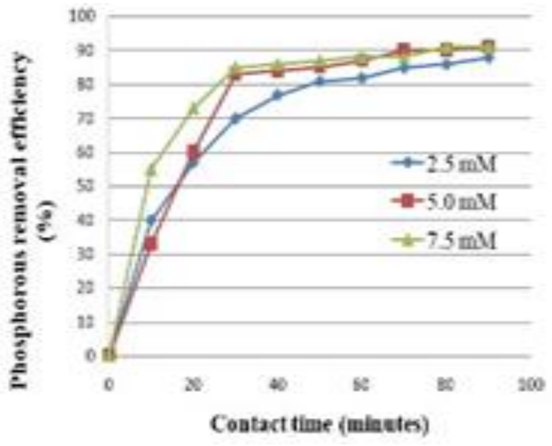


Fig 6 – Effect of 0.25A current on 5 mg/L of initial P concentration

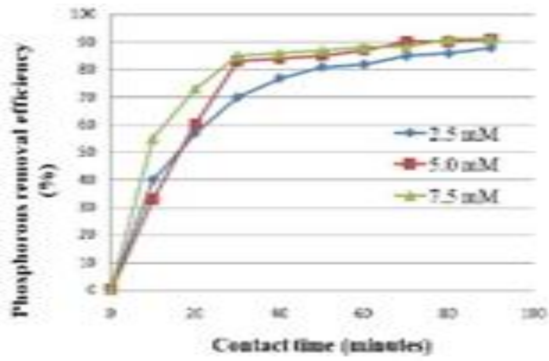


Fig 7 – Effect of 0.5A current on 5 mg/L of initial P concentration

The optimized conditions for all the 3 different initial P concentrations are to be found out by considering the P removal efficiency, electrolyte dosage, current density, reaction time, energy consumption, amount of P adsorbed and sludge quantity. Table 10 shown below gives the optimized condition values.

Table 10 – To determine the optimized condition

Initial P P concentration (mg/L)	Current density (mA/cm^2)	Electrolyte dosage (mM)	Time (min)	Cen(kWh/m^3)	Cp(mg P/g Al)	Sludge quantity (g/m^3)
17	16.67	5	40	5.55	52.07	978.67
11	16.67	2.5	50	9.45	43.91	824
5	16.67	5	30	4.66	40.87	900

A. EFFLUENT CHARACTERISATION

In order to check the EC treated effluent the final characteristics of the effluent are done and given in Table 11.

Table 11 – Effluent characteristics after treatment(All the values mentioned below are in mg/L except pH)

Sl. No.	Parameters	Initial phosphorus concentration (mg/L)		
		17	11	5
1.	pH	7.3	7.1	7.3
2.	Electrical conductivity (mS/cm)	1.420	1.195	0.882
3.	TDS	350	330	325
4.	Chloride	245	240	238
5.	Phosphorus	0.96	0.94	0.87
6.	COD	15	12	18
7.	BOD5 @ 27 º C	9	9	12

V.CONCLUSION

Phosphorus is usually the main limiting nutrient for eutrophication in inland receiving water bodies; therefore, P concentration must be controlled. The purpose of this study was to investigate the effectiveness of EC process using aluminum and stainless steel electrodes for the phosphorus removal of the secondary treated wastewater. 94% P removal efficiency was achieved for 17mg/L of initial P concentration similarly 92 % for 11mg/L and 85% for 5 mg/L.

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