

RSM (Response Surface Methodology) modelling of inter-electrodes spacing effects on phosphate removal

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Abstract—Phosphate contamination of water is a major concern for environmental engineers due to its direct and significant effects on water quality, economy and public health. Hence, controlling phosphate concentration in water sources is one of the priorities of water authorities. Nowadays, various treatment methods, such as biological treatments and adsorption, are used to remove nitrate from water or wastewater. A considerable literature focused on utilizing the electrocoagulation (EC) method to remove phosphate from solutions because it is an environmentally friendly method, and also it can achieve the removal of pollutants within a short time and at a low cost. Thus, the EC method was used here to remove phosphate from water at different inter-electrodes spaces (IES) (4 to 10 mm) and treatment time (TT) (5-55 min) on phosphate removal and the effects of the IES and TT were modelled using RSM. The results showed the best removal of phosphate was 92.5% at I-ES of 4 mm and TT of 50 min. High agreement was noticed between experimental and predicted removals ($R^2=0.984$).

Keywords—Phosphate, Electrocoagulation, water, RSM.

I. INTRODUCTION

Phosphate is a key nutrient that is required to maintain the aquatic life, however the elevated concentrations of phosphate lead to series of environmental problems [1]. For example, eutrophication of water is one of the main environmental problems that resulted from elevated phosphate concentrations [2-4]. The eutrophication dose not only cause changes in water quality, but it also causes significant economic losses. For instance, the eutrophication of freshwater sources in England and Wales results in annual losses estimated by millions of Pound sterling [3, 5-7]. Also, phosphate exerts many health effects [1, 8, 9]. The main sources of phosphate pollution in water are the agricultural runoffs and domestic wastewaters. For instance, agricultural effluents contribute to 25% of phosphates in the freshwaters the UK [3]. The problem of surface water pollution with phosphate, and other pollutants, are getting worse due to many factors such as climate change [10-13] that causes a rapid increase in water consumption [14-17]. The main root or cause of climate change is human activities [18-20]; for example, industrial emissions intensify the global warming [21-28].

Therefore, many researchers used various treatments methods to remediate water and wastewater of phosphate and other pollutants before the final discharge into surface water to avoid adverse effects. The possible treatment methods include the filtrations [29-31], electrochemical [32-34], coagulation [35-37], adsorption [3, 38], bioremediation [39, 40], combined methods [5, 41] hybrid methods [42-44], and electrocoagulation methods [45-47]. The last method acquired high interest because it is cheap [1, 48], safe [49, 50], and fast [51, 52].

This article focuses on the application of EC method to remove phosphate from synthetic water considering the effects of IES and TT. Modelling the effects of IES (4 to 10 mm) and TT (5-25 minutes) on removing phosphate using the EC reactor. RSM (Central Composite Design) method was used in the modelling the effects of IES and TT.

II. MATERIALS AND METHODS

Phosphate contaminated water samples were synthesized by dissolving the required amount of KH_2PO_4 in deionized water to have an initial concentration of phosphate of 100 mg/l.

The samples were treated using an EC reactor with a working volume of 0.665 mL and supplied with four aluminium electrodes having a total active area of 304.4 cm^2 .

The pH of the synthetic water was adjusted to 6 before the treatment. Then, the electrocoagulation treatment was performed at a constant current density of 6 mA/cm^2 , while the IES and TT were changed in the ranges of 4-10 mm and 10-50 minutes, respectively.

The measurement of phosphate concentration was done using LCK standard cuvettes (Hach-Lang) and a spectrophotometer (DR2800).

The modelling of the effects of IES and TT on phosphate removal was done using RSM (Central Composite Design) method that was performed using Minitab software.

III. RESULTS

Initially, the experiments table was prepared using the RSM -Central Composite Design method, as shown in Table 1.

TABLE I. RSM EXPERIMENTS

Run	IES (mm)	TT (min)
1	4.00	50.00
2	4.00	10.00
3	6.50	30.00
4	6.50	30.00
5	6.50	30.00
6	6.50	30.00
7	2.96	30.00
8	9.00	10.00
9	6.50	58.28
10	9.00	50.00
11	6.50	1.72
12	10.04	30.00
13	6.50	30.00

The listed experiments in the table above were run using the EC reactor, and the results of phosphate removal (Ref%) were recorded in Table II.

TABLE II. EXPERIMENTAL PHOSPHATE REMOVAL

Run	IES (mm)	TT (min)	Ref%
1	4.00	50.00	92.5
2	4.00	10.00	54.5
3	6.50	30.00	61.75
4	6.50	30.00	61.1
5	6.50	30.00	62.1
6	6.50	30.00	62.5
7	2.96	30.00	85.5
8	9.00	10.00	14
9	6.50	58.28	83.25
10	9.00	50.00	62
11	6.50	1.72	7.5
12	10.04	30.00	50.2
13	6.50	30.00	61.7

The results above clearly show the removal of phosphate increases with the increase of the TT and with the decrease of the IES. The results also show the best removal of phosphate was 92.5% obtained when the TT was 50 minutes, and the IES was 4 mm. Increasing the TT increases the released amount of aluminium ions, which enhance the removal of phosphate [7]. Similarly, decreasing the IES improves the removal of phosphate by improving the corrosion rate of aluminium electrodes that means the concentration of aluminium ions increases with the decrease of the IES that improves the removal of pollutants [51].

The analysis of the results in Table II yields a model that shown below:

$$Ref\% = 74.6 - 13.36 \times IES + 2.149 TT + 0.447 IES^2 - 0.02111 TT^2 + 0.0500 IES \times TT \quad (1)$$

The model shown above was used to predict the removal of phosphate using the conditions in Table II. The results are shown in Table III. It can be seen from Tables II and III the results are very similar.

To validate the similarity between the actual and predicted nitrate removal, the results were drawn in Fig. 1, and the R² value was calculated. It can be seen R² was 0.9508 that proves

the strong relationship between actual and predicted nitrate removal.

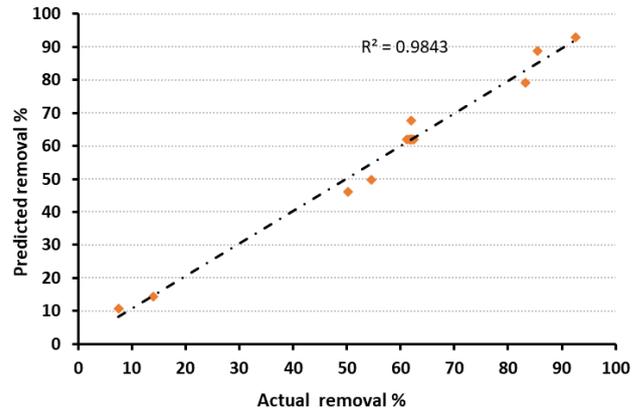


Fig. 1. Relationship between predicted and experimental phosphate removal.

TABLE III. PREDICTED PHOSPAHTE REMOVAL

Run	IES (mm)	TT (min)	Predicted Ref%
1	4.00	50.00	92.99
2	4.00	10.00	49.69
3	6.50	30.00	61.87
4	6.50	30.00	61.87
5	6.50	30.00	61.87
6	6.50	30.00	61.87
7	2.96	30.00	88.84
8	9.00	10.00	14.45
9	6.50	58.28	79.13
10	9.00	50.00	67.74
11	6.50	1.72	10.83
12	10.04	30.00	46.07
13	6.50	30.00	61.87

The combined effects of the TT and IES on phosphate removal by the EC unit are shown in Fig. 2.

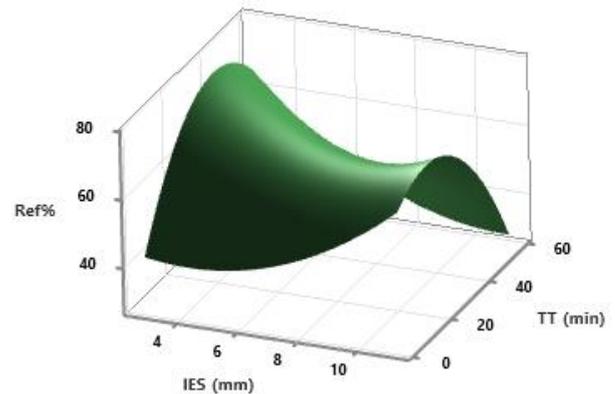


Fig. 2. Relationship between predicted and experimental phosphate removal.

Finally, phosphate concentration in water and wastewater could be monitored using advanced technologies, such as electromagnetic waves [53-55], such as the use of microwaves [56-61]. Therefore, for future studies, the use such advanced methods to assess the phosphate concentration in water and wastewater.

IV. CONCLUSION

The obtained results from the current study indicated that the EC method was efficient in the removal of phosphate from water. Increasing the TT positively affects the removal of phosphate from water. On the other hand, increasing the IES negatively affects the removal of phosphate from water.

Therefore, phosphate removal could be improved by keeping the TT at the longest value, while the IES must be kept at low values.

The RSM (Central Composite Design) method is also proved its suitability for modelling phosphate removal from water.

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