

Removal of Phosphorous (P) from Sewage Water by Phytorid Sewage Treatment Plant: a Study using the Response Surface Methodology

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ABSTRACT: Removal of phosphorous (P) from sewage water by phytorid sewage treatment plant was studied at Agriculture College, Maharajbag, Nagpur to examine the efficacy of the phytorid sewage treatment plant in P concentration removal from the sewage water, and to determine the optimum condition using response surface methodology during 2013-14. A Box-Behnken model was employed as an experimental design. The effect of three independent variables hydraulic loading or flow (50 – 150 m³. d⁻¹), dilution (10 - 80 %) and spatial length (16 - 100 %) was studied on P concentration removal from the sewage water in bench mode of the experiment. The optimal conditions of the P removal were found to be flow: 55.74 m³ d⁻¹, dilution: 40.59 per cent and spatial length: 100 per cent. Under these experimental conditions, the experimental P concentration removal obtained was 1.321 mg L⁻¹. The proposed model equation using the RSM has shown good agreement with the experimental data, with a correlation coefficient (R²) of 98.21 per cent. The result showed that optimised condition could be used for the efficient removal of the P from the sewage water.

KEYWORDS: Response surface methodology, Box-Behnken experimental design, sewage water, optimization)

I. INTRODUCTION

Throughout the world, fluvial discharges of nutrients and sediments have increased due to increasing fertilizer applications to croplands (e.g. Jordan and Weller, 1996), increasing concentration of livestock waste production (e.g., Sims and Wolf, 1994) and land-cover changes that enhance erosion (Woodward and Foster, 1997). Excess phosphorous in effluents can leach and pollute groundwater under continuous sewage effluent use for long periods. Phosphorus is an essential element for plant life, but when there is too much of it in water, it can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes. Complex nature of sewage water made it difficult to obtain the significant P removal from the sewage water. Sewage treatment plant based on CW's is now well-established methods for wastewater treatment in tropical climates (Burchellet *et al.*, 2007). Recent research has shown that sewage treatment plant based on constructed or restored wetlands can remove sediments and nutrients from nonpoint sources, including agricultural discharges (Fleischer *et al.*, 1994). Widespread restoration of wetlands has been suggested as part of a plan for reducing nitrogen releases from the Mississippi river basin (Mitschet *et al.*, 2000). Removal efficiency of constructed wetland with phytoplants (cattail and cyperus), plant density (4 and 22.5 m²), and hydraulic retention time (2.2 and 6.6 days), for NO₃-N were in the range of 44.1-67.2 % (Yuan *et al.*, 2005).

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Nutrient removal by constructed wetlands has been extensively studied for their use in wastewater treatment (Kadlec and Knight, 1996). Variability of water flow may diminish the ability of wetlands to remove nutrients and sediments, as removal capacities may be temporarily overwhelmed during short-lived high flow events (e.g., Kovacic *et al.*, 2000). There is also a need to find ways to capture P from wastewater and return it to agriculture as a nutrient source in order to balance inputs and outputs of P in agricultural systems (Sharpley, 1999). Researchers have examined the use of various materials as potential substrates to improve P removal by wetland treatment systems (Brix *et al.*, 2001). Other researchers have investigated the addition of P-sorbing materials in separate rechargeable cells to improve the ability and sustainability of constructed wetlands to remove phosphorus from wastewater (Arias *et al.*, 2003). By sequestering P with non-toxic materials, it could possibly be reused by agriculture. The use of by-products in co-treatment cells could be a low-cost way to improve the performance and longevity of CW or could be used to reduce the wetland area required for a given level of treatment.

In absorption based methods, it is desirable to have knowledge of the process variables and their influence on absorption capacity to maximise concentration removal of the contaminants in sewage treatment plant. In the present study, the investigation propose to use a phytoid sewage treatment plant to enhance P removal by physical, chemical and biological treatment. Phytoid bed is a scientifically developed, sustainable constructed wet land treatment methodology to treat the domestic city sewage (NEERI, 2005). Response surface methodology (RSM) has been applied to optimise and evaluate interactive effects of independent factors in numerous chemical and biochemical processes. It is essential that experimental design methodology is an economic way for extracting the maximum amount of complex information, a significant experimental time saving factor and moreover, saves the material used for analyses and personal costs as well (Kincl *et al.*, 2005).

Presently, much attention has been paid to phytoid sewage treatment because of many advantages such as simple construction works on gravity, no electric power requirement, scalable technology, easy to maintenance, adds to the aesthetics, cost effective (NEERI, 2005). The objective of the present study is to find the optimum condition for efficient P removal from sewage water through phytoid sewage treatment plant by applying Box-Behenken design and response surface methodology to understand the effect of various parameters and their interaction.

II. REALTED WORK

1. Leader (2005) investigated eighteen wastewater treatment systems operated for one year to investigate phosphorus (P) removal. Systems paired co-treatment reactors containing iron or calcium drinking water treatment residuals with vertical-flow constructed wetland mesocosms planted with *Schoenoplectus tabernaemontani* (K.C Gmel.) Palla. for secondary municipal wastewater, soluble reactive phosphorus (P) concentrations were reduced from 0.70 to 0.03 mg L⁻¹ or (95 %) or 0.01 mg L⁻¹ (98 %) by systems with the calcium or iron co-treatments, respectively (compared to 0.09 mg L⁻¹ or 87 % by controls). Total P (TP) concentrations were reduced from 1.00 to 0.07 mg L⁻¹ (93 %) and 0.05 mg L⁻¹ (95 %) by the same treatments (compared to 0.16 mg L⁻¹ or 84 % by controls).

2. Mohamed (2005) tested the suitability of constructed wetlands (reed bed system) a pilot project, a technology for the treatment of wastewater in Syria and had the objective to test the suitability of constructed wetlands for the treatment of wastewater. The COD, P and BOD removal efficiencies found were 85, 85 and 68 percent respectively.

3. Can *et al.* (2006) studied optimization and the removal efficiency of Ni(II) with 23 full-factorial central composite design with the three variable initial Ni(II) concentration Co (10–30 mg/l), pH (2.5–6.5) and biomass concentration (5–25 g/l) and , concluded that the optimum removal efficiency of Ni(II) was calculated as 100%. The experimental conditions at this optimum point were pH = 6.17, m = 18.8 g/l, Co = 11.175 mg L⁻¹ and corresponding removal efficiency of Ni(II) was 99.91%.

Masi *et al.* (2010) reported that to establish appropriate designs for treatment of segregated domestic black (BW) and grey water (GW). CW removal efficiencies of TSS, COD, BOD, N-NH₄⁺, N-NO₃, N_{tot}, total coli forms (TC) were evaluated in four Technological Demonstration Centers in Egypt, Morocco, Tunisia and Turkey. A very efficient COD

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reduction (up to 98 %) and nitrification (92–99 %) was achieved for BW and GW in all systems. CW effluent concentrations were below 15 mg L^{-1} for BOD, 1 mg L^{-1} for N-NO_3 and 0.5 mg L^{-1} for N-NH_4^+ together with acceptable TC counts.

4. Belligno *et al.* (2001) conducted the research using an integrated approach that included the assessment of plant action; the potential of treated waters for reuse in irrigation; interaction with soils; disposal/combustion of plants in power generation; social and economic implications; and the expected effects on the ecosystem. Results of the purifying action of the constructed wetlands were not always consistent. The total suspended solids were reduced by 55 - 95.4 per cent; BOD_5 by 58 - 92 per cent; N by 11 - 68.3 per cent; P by 17.2 - 25.4 per cent; Fe by 31 per cent; coli bacteria by 25 - 85 per cent; and faecal coli bacteria by 13 - 90 per cent.

5. Jordan *et al.* (2003) studied removal of pollutants by restored wetlands of 1.3 ha. in Maryland, USA. The most removal occurred in the first year, which was 59 per cent of the total P, 38 per cent of the total N, and 41 per cent of the total organic C it received. However, in the second year, which lacked a drying period, there was no significant ($p > 0.05$) net removal of total N or P, although 30 per cent of the total organic C input was removed.

6. Kurniadie (2011) studied the removal of COD, BOD, $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NH}_4\text{-N}$, total-N, $\text{PO}_4\text{-P}$, total coli form bacteria, pH, O_2 and settle able solids from the constructed wetland with a vertical flow system to treat sewage from farm house by using aquatic macrophytes (*Phragmites karka*). The average treatment efficiencies during the period from August 2009 to January 2010 for BOD_5 , COD, $\text{NH}_4\text{-N}$, total-N, $\text{PO}_4\text{-P}$ and total coli form bacteria were 76.03, 78.89, 88.18, 71.70, 91.06 and 99.45 per cent respectively.

III. MATERIAL AND METHODS

Treatment Plant

Scientific study was carried out to convert sewage water into irrigation water for agricultural and gardening purpose. A pilot project in collaboration with NEERI technology was undertaken as a model, and the treatment plant was constructed at Maharaj bag campus of Agriculture College, Nagpur, Maharashtra, India. The designed capacity of the plant was $100 \text{ m}^3 \cdot \text{d}^{-1}$ of treated water. As the sewage water flow was $426 \text{ m}^3 \cdot \text{h}^{-1}$, it was not possible to construct the phytoid constructed wet land directly across the flowing river for large space and fund requirement. Therefore, as suggested by Massuodet *et al.* (2009), the intake well was designed and constructed at the bank of the river. A screen was provided to avoid the entry of garbage material in the intake well. A pump was selected as per designed capacity of the treatment plant for lifting the raw sewage water. Throughout the length of phytoid sewage treatment plant (from screening chamber to storage tank), a uniform gradient of 1% was provided for flow of sewage water through the sewage treatment plant.

Experimental Design

The Phytoid sewage treatment plant was designed for $100 \text{ m}^3 \cdot \text{d}^{-1}$ capacity. However, for maximum removal of P from the sewage treatment plant, independent variables ranges selected were $50\text{-}150 \text{ m}^3 \cdot \text{d}^{-1}$ for sewage flow (hydraulic loading), 10–80 per cent for dilution and 16–100 per cent for spatial length of the sewage treatment plant. Surface response modelling with Box-Behnenken experimental design widely used for controlling the effects of parameters in any processes was used for the pre-treatment and optimization (Bhanarkaret *et al.*, 2011). Use of RSM decreased the number of trials, which otherwise would have been required in full factorial methods for the same object, thereby saving time and material resources. The experimental plan consisted of base run 15, and independent variables were studied at three different levels of low (-1), medium (0) and high (+1). Box-Behnenken experimental design has the advantage of fewer trials (15 basic run) than that would be required in full factorial design (27 runs). The removal of P concentration was taken as response (Y) of the experimental design. Furthermore, the analysis performed on the results

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is easily realized and experimental errors are minimized due to 3D response. Statistical methods measured the effects of change in operating variables and their mutual interactions on process.

Response surface methodology

Statistical designs are powerful tools used to study the main as well as the interactive effects of different process variables on a process. Among them, response surface methodology (RSM) is a collection of certain statistical techniques for designing experiments, building models, evaluating the effects of factors and searching for optimal conditions of desirable responses. The advantages of adopting RSM: (1) it provides more information on the experiment than unplanned approaches; (2) it reduces number and cost of experiments; (3) it makes possible to study the interactions among experimental variables within the range studied, leading to a better understanding of the process; (4) it facilitates to determine operating conditions necessary for the scale-up of the process. Its greatest applications have been in industrial research, particularly in situations where most of variables influencing the system feature (Myers and Monntgomery, 2002).

Experimental design for absorption studies

In this study, the Box–Behnken experimental design was chosen for finding out the relationship between the response functions (P removal) and independent variables (Hydraulic loading, dilution indicating initial concentration of sewage and spatial length of the sewage treatment plant for three different size fractions of 50 - 150 m³.d⁻¹, 10 – 80 per cent ,16-100 per cent respectively. In order to study the effects of three independent variables on pollutant concentration removal of the COD, BOD, NPK, turbidity, TDS, micronutrients and heavy metals; batch runs were conducted at different combinations of the process parameters using Box-Behnken designed experiments. The hydraulic loading i.e. flow range studied was between 50 to 150 m³.d⁻¹, dilution (initial concentration of sewage) was kept between 10 to 80 per cent and the spatial length was varied between 16 and 100 per cent (Table 1). Box–Behnken design is rotatable second-order designs based on three-level incomplete factorial designs. The special arrangement of the Box–Behnken design levels allows the number of design points to increase at the same rate as the number of polynomial coefficients. In order to obtain the optimum condition for P removal, three independent parameters were selected (Bhanarkar, 2011) and are presented in Table 1.

Table 1. Experimental range and levels of variables

Variables	Unit	Code	Range and Levels		
			Low level (-1)	Centre (0)	High level (1)
Hydraulic Loading (flow)	(m ³ d ⁻¹)	X ₁	50	100	150
Dilution (Initial concentration of sewage)	(%)	X ₂	10	45	80
Spatial length	(%)	X ₃	16	58	100

The operating ranges for hydraulic loading i.e. flow (X₁), dilution (X₂) and spatial length (X₃) were determined by an iterative method. The relationship between the parameters and responses were determined using Box-Behnken design under RSM. In this study, the experimental plan consisted of 15 base run, and the independent variables were studied at three different levels of low (-1), medium (0) and high (+1). Box-Behnken design presents an approximately rotatable design with only three levels per variable and combines a fractional factorial with incomplete block design excluding the extreme vertices (Aslan and Cebeci, 2007). The Box-Behnken design has good performance with less error. The percentage of P removal was taken as a response (Y) of the experimental design. If all variables are assumed to be measurable, the response surface can be expressed as follows:

$$Y = f(x_1; x_2; x_3; \dots ; x_k) \dots \dots \dots (1)$$

Where, Y is the answer of the system, and x_i are the variables of action called factors.

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The goal is to optimize the response variable Y. It was assumed that the independent variables are continuous and controllable by experiments with negligible errors. It was required to find a suitable approximation (equation) for the true functional relationship between independent variables and the response surface (dependable variable). Usually, a second-order model is utilized in response surface methodology. In the optimisation process, the responses can be simply related to chosen variables by linear or quadratic models. A quadratic model, which also includes the linear model, is given below:

$$Y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 + \sum_{i=1}^k \sum_{j=1}^k \beta_{ij} x_i x_j + \varepsilon \quad \text{----- (2)}$$

Where, Y = Response,
 x_1, x_2, \dots, x_k = Coded independent variables,
 β_i, β_{ii} and β_{ij} = Linear, quadratic and interaction coefficients, respectively,
 β_0 = Constant, and ε = Random error.

Trials were performed in triplicate. Minitab 16 Free trial version software package for regression and graphical analysis were used for analyses of the data. In all calculation, spreadsheets of Microsoft Excel 2007 were used as ODBC (Open Database Connectivity) data source running under windows.

Statistical analysis

The significance of the independent variables and their interactions was tested by the analysis of variance (ANOVA). Results were assessed with various descriptive statistics such as t-ratio, p-value, F-value, degrees of freedom (df), coefficient of variation (CV), coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), sum of squares (SS), mean sum of squares (MSS), Mallows' C_p statistic test to reflect the statistical significance of the quadratic model. The tabulated value of F statistic corresponding to df was obtained at desired probability level (i.e. 0.05 significance level or 95% confidence).

IV. RESULTS AND DISCUSSION

P Removal

The results of P concentration removal along with experimental conditions are given in Table 2. By applying multiple regression analysis on the design matrix and responses given in Table 2, approximate uncoded function for P concentration removal applicable for the treatment plant under study is given in following equation (Bhanarkaret *et al.*, 2011):

$$Y = -1.155 + 0.020X_1 + 196.310 \times 10^{-4} X_2 + 30.97 \times 10^{-4} X_3 - 8.72 \times 10^{-5} X_1^2 - 3.73 \times 10^{-5} X_2^2 + 1.13 \times 10^{-5} X_3^2 - 2.91 \times 10^{-5} X_1 X_2 - 4.23 \times 10^{-6} X_1 X_3 - 6.27 \times 10^{-5} X_2 X_3 \quad \text{..... (3)}$$

Where, Y is the pollutant concentration removal; and X_1, X_2, X_3 are corresponding uncoded variable of flow (hydraulic loading), dilution and spatial length, respectively.

Table 2. Box-Behnken Experimental Design Matrix with Variable and Pollutant Removal

Factors: 3 Replicates: 2		Base runs: 15		Total runs: 30 Base blocks: 1			
Total blocks: 1		Center points: 6		Design Table (randomized)			
Run	Blk	A	B	C			
Run order	Coded variable			Uncoded variable			Response
	X1	X2	X3	Flow(m ³ /day)	Dilution (%)	Spatial (%)	P
1	+	-	0	150	10	58	0.20
2	-	-	0	50	10	58	0.00

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3	+	0	-	150	45	16	0.53
4	0	+	-	100	80	16	1.10
5	-	+	0	50	80	58	0.78
6	0	-	+	100	10	100	0.46
7	-	0	-	50	45	16	0.35
8	0	0	0	100	45	58	0.61
9	0	-	+	100	10	100	0.42
10	0	+	+	100	80	100	0.98
11	+	-	0	150	10	58	0.15
12	-	0	-	50	45	16	0.38
13	0	0	0	100	45	58	0.68
14	+	0	-	150	45	16	0.48
15	0	0	0	100	45	58	0.71
16	0	-	-	100	10	16	0.16
17	0	0	0	100	45	58	0.61
18	0	0	0	100	45	58	0.72
19	-	-	0	50	10	58	0.00
20	-	+	0	50	80	58	0.72
21	+	0	+	150	45	100	0.53
22	0	+	+	100	80	100	0.96
23	0	0	0	100	45	58	0.71
24	-	0	+	50	45	100	0.52
25	0	-	-	100	10	16	0.13
26	-	0	+	50	45	100	0.41
27	+	0	+	150	45	100	0.61
28	+	+	0	150	80	58	0.74
29	0	+	-	100	80	16	0.98
30	0	+	0	100	80	58	0.84

Model Statistical Tests

The ANOVA was conducted as the analysis of variance, to test the significance of the developed model (Sen&Swaminathan, 2004). The summary of ANOVA of the regression model presented in Table 3 indicated that the model equation could be used adequately to describe the concentration removal of P under a wide range of operating conditions. F-value of 122.24 being greater than the tabulated value (F tab- 4.1) implied that the model was significant. The probability value (p-model < F = 0.000, or below 0.0001) was less than 0.05, indicating that the quadratic model was highly significant. A fairly high value of R² (98.30%) suggested that most of the data variation was explained by the regression model.

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Table 3. Analysis of variance (ANOVA) of the response surface quadratic model for the prediction of P concentration removal

Source	DF	Sum of square	Mean square	F- value	P-value	Remark
Regression	9	2.38738	0.26526	122.24	0.000	Significant
X ₁	1	0.03715	0.03715	17.12	0.001	Significant
X ₂	1	1.85436	1.85436	854.50	0.000	Significant
X ₃	1	0.03842	0.03842	17.70	0.000	Significant
X ₁₂	1	0.34862	0.35068	161.59	0.000	Significant
X ₂ ²	1	0.01655	0.01540	7.10	0.015	Significant
X ₃ ²	1	0.00294	0.00294	1.36	0.258	No significant
X ₁ X ₂	1	0.02081	0.02081	9.59	0.006	Significant
X ₁ X ₃	1	0.00063	0.00063	0.29	0.596	No significant
X ₂ X ₃	1	0.06790	0.06790	31.29	0.000	Significant
Residual Error	20	0.04340	0.00217			
Lack-of-Fit	3	0.00747	0.00249	1.18	0.347	No significant
Pure Error	17	0.03593	0.00211			
Total	29	2.43078				

S = 0.0465844 SSe = 0.04

MSSe = 0.00217

CV=8.92

R-Sq = 98.21(%)

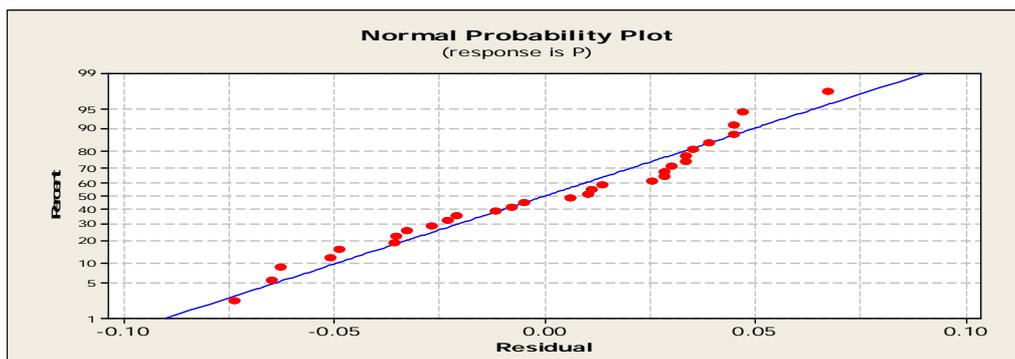
R-Sq (pred) = 96.04(%)

R-Sq (adj) = 97.41(%)

Moreover, high value of the adjusted regression coefficient (R^2_{adj} -97.54%) indicated the capability of the developed model to satisfactorily describe the system behaviour within the studied range of operating parameters. Similar results were earlier reported by Can *et al.*(2006) and Zhang *et al.* (2010). The value of R^2_{adj} was higher than that of R^2 . A similar pattern has been reported by others for the second-order RSM experiments based on Box-Benhken (Khajeh, 2011) and central composite designs. Further, a relatively low value of the coefficient of variation (CV-9.88%) indicated good precision and reliability of the conducted experiments, similar to earlier reported by Ahmad *et al.* (2005).

Model adequacy check

Adequacy check of the proposed model is an important part of the analytic procedure. Good adequacy can ensure the model to provide an adequate approximation to the real system (Korbahti and Rauf, 2008).



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Fig.1. Normal probability plot of the residuals of P

The normal probability of the residuals Fig.1 suggests that almost no serious violation of the assumptions underlying the analysis, and it confirmed the normality assumptions and independence of the residuals. Moreover, the comparison of the residuals with the error variance showed that none of the individual residual exceeded the value twice of the square root of the error variance. Similar findings were reported by Sen and Swaminathan (2004)

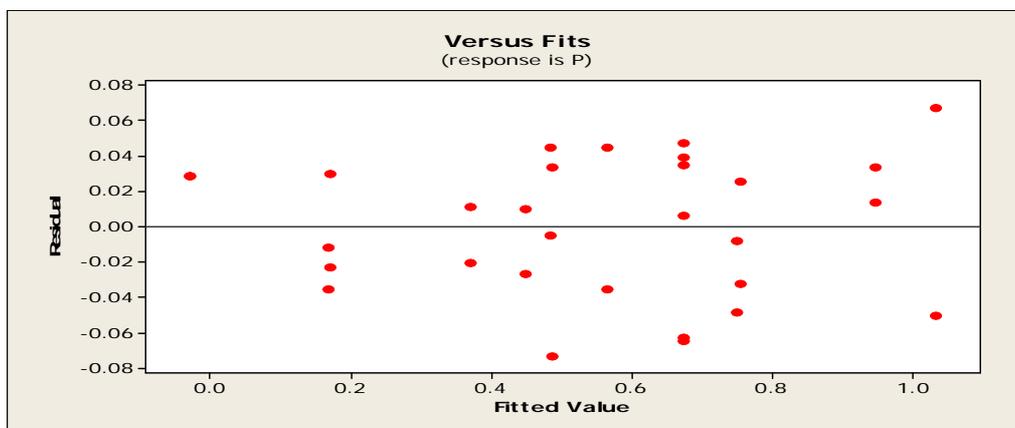


Fig.2. Internally studentized residuals vs. Predicted value plot for P

The plot presented in Fig. 2 tests the assumption of constant variance. The points are randomly scattered, and all values are lying within the range of -0.07 and $+0.07$. Values beyond -0.08 and $+0.08$ are considered as the top and bottom outlier detection limits. Accordingly it was inferred that developed response transformation was appropriate and developed quadratic model is successful for capturing the correlation between the influencing parameters of P removal process.

Model significance test

The result of student t-test and p-value conducted to evaluate the significance of the quadratic model coefficient are listed in Table 4. The t-value is the ratio of estimated parameter effect, and estimated parameter standard deviation. The parameter effect is estimated as twice the regression coefficient value for that parameter. The p-value is used as a tool to check the significance of the coefficient. The larger the magnitude of t value and smaller the p value, significant is the corresponding parameter in the regression model as reported by Yeltilmezsoy *et al.* (2009).

Table 4. Multiple regression results and significance of the components for the quadratic model of P

Term	Coefficient	Standard error	Effect	t-ratio	PC (%)
Constant	0.6750	0.0190	1.350	-----	-----
X ₁	0.0482	0.0117	0.096	8.28	1.56
X ₂	0.3400	0.0117	0.680	58.46	77.67
X ₃	0.0490	0.0117	0.098	08.41	1.60
X ₁ ²	-0.2180	0.0171	-0.436	-25.42	14.60
X ₂ ²	-0.0457	0.0171	-0.091	-5.33	0.69
X ₃ ²	0.0200	0.0171	0.0399	2.33	0.12
X ₁ X ₂	-0.0510	0.0165	-0.102	-6.19	0.87
X ₁ X ₃	-0.0089	0.0165	-0.018	-1.08	0.03

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$X_2 X_3$	-0.0921	0.0165	-0.184	-11.19	2.84
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Results showed that all the linear and quadratic terms except length (X_3)*length (X_3) are statistically significant ($p < 0.05$). Similarly all interactive terms except Flow(X_1)*length (X_3) were found statistically significant. Moreover, first order main effect of independent variables namely flow (X_1), dilution (X_2) and length (X_3) were found to be more significant than their respective quadratic effects (X_1^2 , X_2^2 and X_3^2) followed by interaction effect of all the three independent variables. The t- and p-value (Table 3 and 4) suggested that the linear term dilution (X_2) was found to be the most significant component of the regression model for the present application, whereas, the quadratic term flow (X_1) and Length (X_3) showed the lowest effect on the P removal.

PC of each of the individual terms in the final model computed using the sum of squares (SS) values of the corresponding term are presented in Table 4. Similar results are reported by Singh *et al.* (2011). As evident from Table 4, the first order terms dilution (X_2) showed the highest level of significance with a contribution of >80.84 % as compared to other components. Fig.3 shown the total percentage contribution (TPC) of the possible first order, quadratic and interactive component calculated according to Menget *al.* (2007).

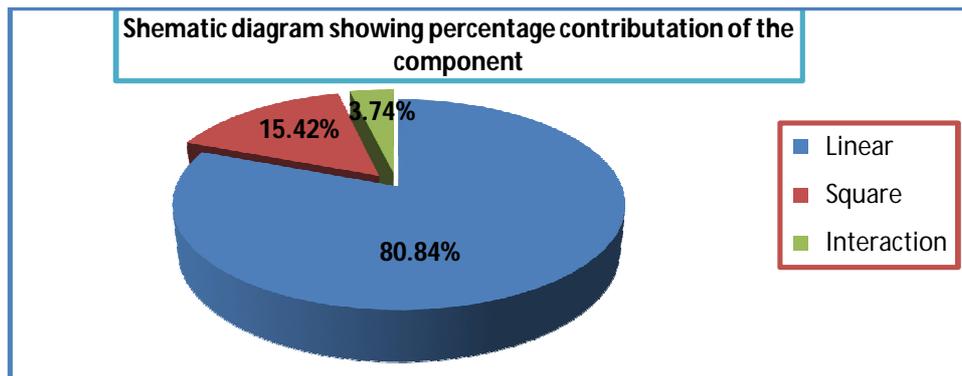


Fig.3. Schematic diagram showing percentage contribution of the component

Results revealed that among the calculated TPC values, first order terms had the highest level of significance with a total contribution of 80.84 per cent as compared to other TPC values. This was followed by the TPC of quadratic terms with a total contribution of 15.42 per cent. The TPC of interactive terms showed the lowest level of significance with a total contribution of 3.74 per cent, indicating that the interactive components showed a little effect in prediction of the P removal. Hence, TPC values also proved that the first order terms have a direct relationship on the dependent variable.

Optimization of Experimental Condition for P Removal

In order to gain better understanding of the influence of the independent variables and their interactions on the dependent variable, response surface plots for the measured responses were drawn based on the quadratic model as suggested by Yetilmezsoy *et al.* (2009) Fig. 4 exhibits the response contour plots as the functions of two independent variables keeping other variable fixed at the centre level. The overall concentration of P has observed to be reduced in the sewage water but due to decomposition of organic matter in oxidation process there is increase in absolute P as explained in the contour graph.

It can be seen from Fig. 4(a) that the concentration of P was increased slightly with increasing the hydraulic loading of sewage might be due to the higher P concentration in sewage. Similarly P concentration was found increased due to increase in the dilution which might be due to P bounded in organic matter was released during the decomposition in oxidation process for which oxygen was provided by fresh water. Similar results are reported by Leader (2005) and Jordan *et al.* (2003). Absolute value increase in 'P' as observed in the contour plot was therefore increased (Vimazalet *al.*, 2007). But overall there is reduction in P concentration.

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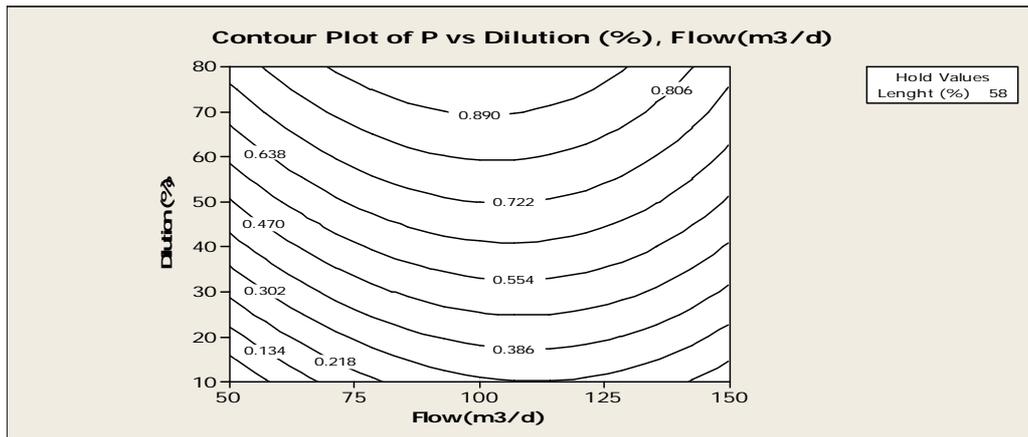


Fig.4(a). Contour plot showing effect of two independent variables (Length (%) was held at their respective centre level) (a) Dilution (%) and flow ($m^3 d^{-1}$)

From Fig. 4(b) it is evident that the concentration of P found increasing from 0.432 mg L^{-1} to 0.496 mg L^{-1} with increasing length from 50 to 100 per cent. This might be due to the release of P in the treatment plant due to decomposition of organic matter through oxidation process by addition of oxygen of atmosphere from phyto plants through the roots. Similarly concentration of P was increased from 0.432 mg L^{-1} to 0.656 mg L^{-1} with increase in flow in the treatment plant from $50 \text{ m}^3 \text{ d}^{-1}$ to $100 \text{ m}^3 \text{ d}^{-1}$ might be due to higher P concentration in sewage. Whereas the concentration of P was found decreased when hydraulic loading increased from 100 mg L^{-1} to 150 mg L^{-1} . The release quantity of P was very small therefore did not contributed to overall concentration of P in treated water and thereby the absolute value increase in P as observed in the contour plot (Zhao *et al.*, 2008).

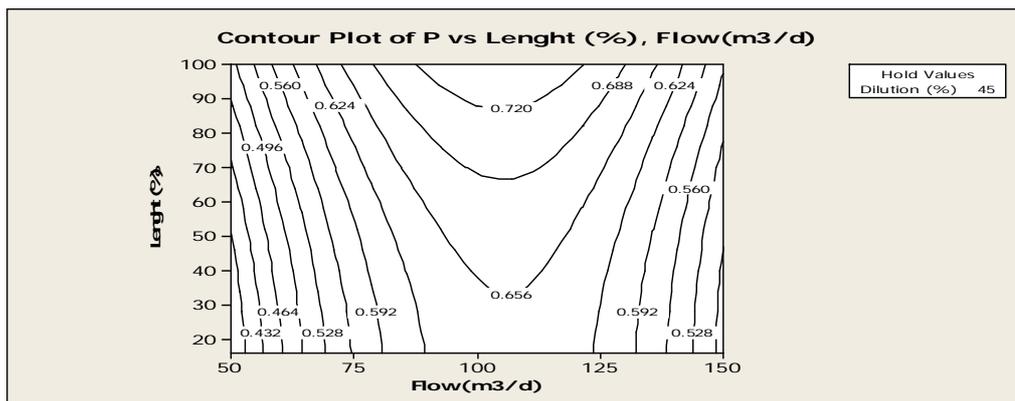


Fig.4(b). Contour plot showing effect of two independent variables (Dilution (%) was held at their respective centre level) (b) Length (%) and flow ($m^3 d^{-1}$)

As depicted in Fig. 4 (c) it is clearly observed that the concentration of P slightly increased from 0.20 mg L^{-1} to 0.44 mg L^{-1} with increasing spatial length from 10 to 100 percent. This increase in P concentration according to the length might due to addition of oxygen from plants through the roots and thereby increasing the absolute concentration of P in the treatment plant. Similarly it is also evident that P concentration was increased from 0.30 mg L^{-1} to 0.98 mg L^{-1} with increase in dilution percentage in the treatment plant from 10 to 80 percentages. The reason for the increase in the P concentration with increase in dilution might be due to the addition of the oxygen and thereby release absolute quantity of P in the treatment plant due to decomposition of organic matter in sewage. The free available P from sewage has

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been up taken by the plants in initial bed length of the phytoid contributed towards P removal but due to oxidation and thereby decomposition of the organic matter there is absolute increase in value of 'P' as observed in contour plot.

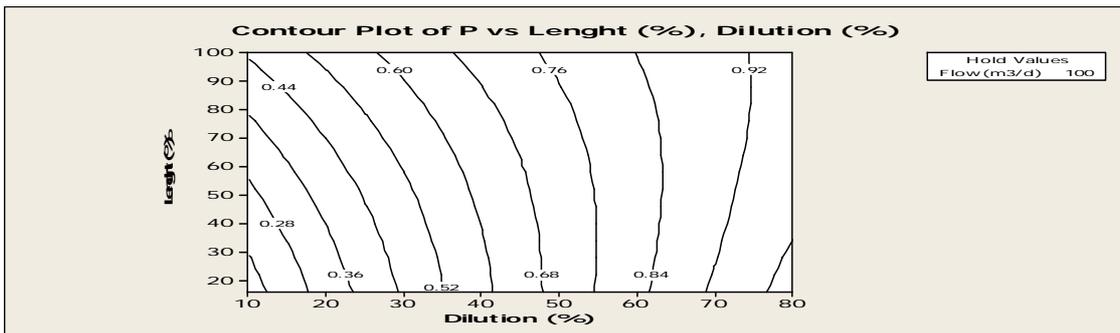


Fig.4(c). Contour plot showing effect of two independent variables (Flow $m^3 d^{-1}$ was held at their respective centre level) (c) Length (%) and dilution (%)

Response Optimization

The optimization of P by using the response optimizer was carried out for independent variable for the value of N = 0.5. The optimized global solution for the independent variable found was flow = $55.74 m^3 d^{-1}$, dilution = 40.53 percent and spatial length = 100 percent with the composite desirability equal to 1.000 as depicted in Fig.5. Similar results were suggested earlier by Marufet *al.* (2011) in optimizing the condition for the extraction of b-carotene, phenolic and ascorbic acid content from yellow-fleshed.

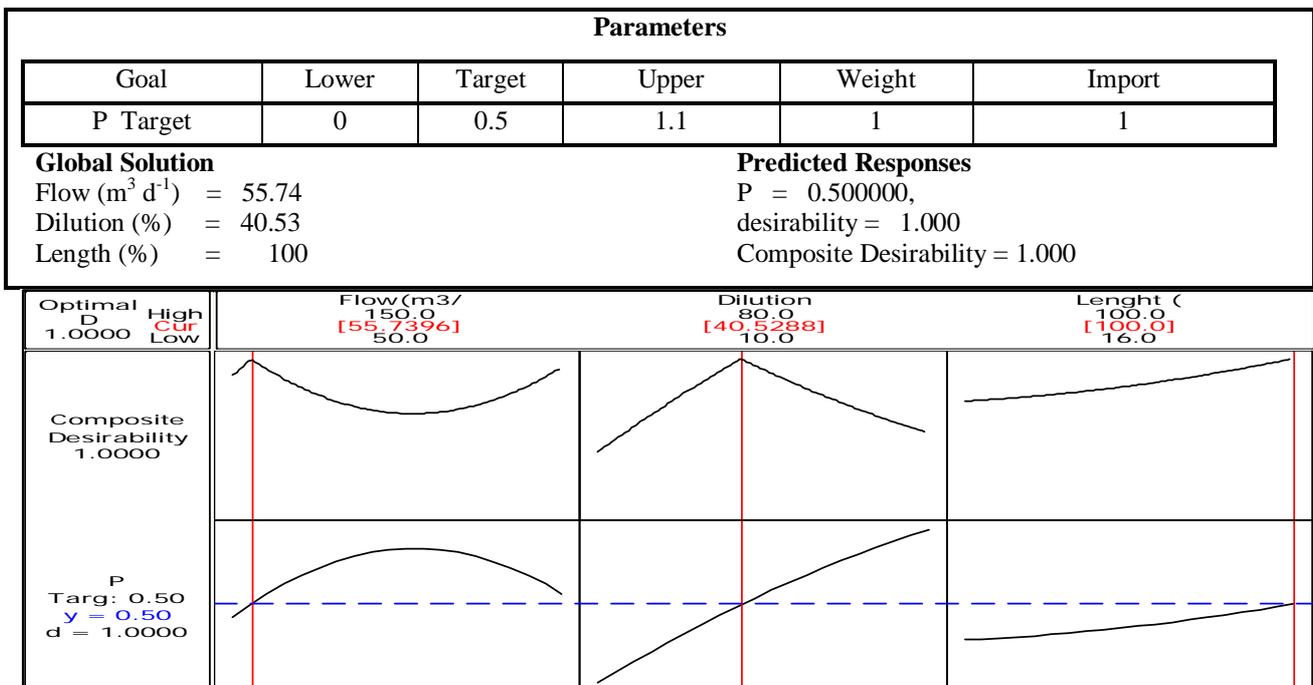


Fig.5. Contour plot showing the optimizing condition of the P

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Predicted vs. Actual

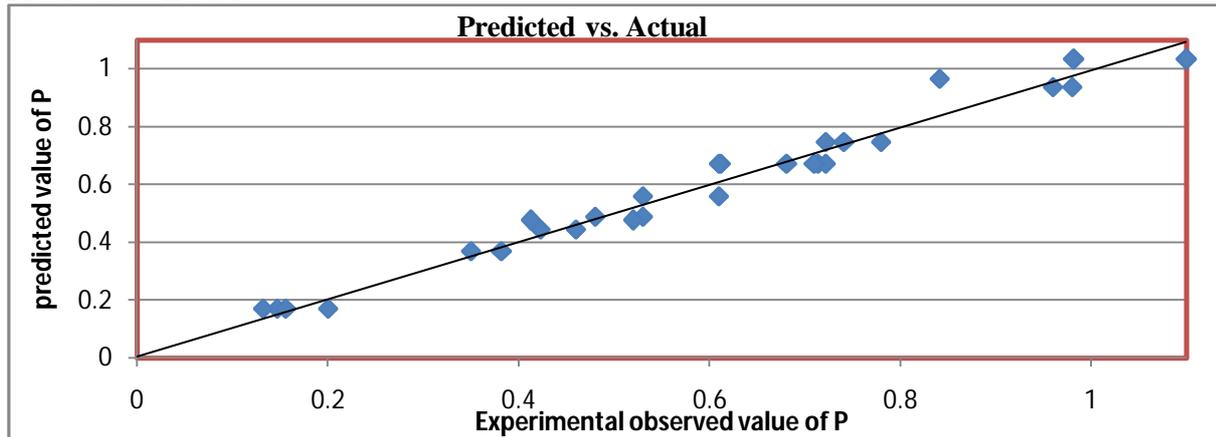


Fig.6. Plot showing the experimental observed value versus predicted value of the P

The diagnostic plots shown in Fig. 6 were used for estimating the adequacy of the regression model. The observed and predicted values of P removal were in well agreement. The points cluster around the diagonal line indicates developed quadratic model is successful in capturing the correlation between the influencing parameter of P removal process.

V. CONCLUSION

Application of response surface methodology and Box– Behnken design from the point of view P concentration removal from sewage water is discussed. Three-level three-factorial Box–Behnken experimental design was applied in the study. Predicted values of P concentration removal obtained using model equations were in good agreement with the experimental values ($R^2 - 0.982$). In order to gain a better understanding of the effect of the variables on P concentration removal, the predicted models were presented as contour graphs. This study proved that Box–Behnken design and response surface methodology could economically and efficiently be applied for modelling of some pollutant concentration removal from the phytorid sewage treatment plant.

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