e ISSN-0976-7223 | Visit Us - *www.researchjournal.co.in* DOI : 10.15740/HAS/IJAE/7.2/365-372

RESEARCH PAPER **International Journal of Agricultural Engineering | Volume 7 | Issue 2 | October, 2014 | 365–372**

Removal of tubidity from sewage water by phytorid sewage treatment plant : A study using the response surface methodology

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Received : 15.03.2014; **Revised :** 10.08.2014; **Accepted :** 24.08.2014

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ABSTRACT : Removal of the turbidity from the sewage water by phytorid sewage treatment plant has been studied on Agril College Maharajbag, Nagpur during the year 2012-2013. The objective of this investigation was to study the efficacy of the phytorid sewage treatment plant in turbidity removal from the sewage water and to determine the optimum condition using the response surface methodology. A Box-Behnken model has been employed as an experimental design. The effect of three independent variables namely hydraulic loading *i.e.* flow (50 - 150 $m^3 d^{-1}$), dilution (10 - 80 %) and spatial length (16 – 100 %) has been studied on the turbidity removal from the sewage water in bench mode of the experiment. The optimal conditions of the turbidity removal were found to be flow: 150 $m^3 d^{-1}$, dilution: 65.13 per cent and spatial length: 87.65 per cent. Under these experimental conditions, the experimental turbidity removal obtained was 7 mg L^{-1}. The proposed model equation using the RSM has shown good agreement with the experimental data, with a correlation co-efficient (R^2) of 0.9743. The result showed that optimised condition could be used for the efficient removal of the turbidity from the sewage water.

KEY WORDS : Turbidity, Response surface methodology, Box-Behnken experimental design, Sewage water, Optimization

HOW TO CITE THIS PAPER : Mhaske, A.R., Taley, S.M. and Biniwale, R.B. (2014). Removal of tubidity from sewage water by phytorid sewage treatment plant : A study using the response surface methodology. *Internat. J. Agric. Engg.*, **7**(2) : 365-372.

It is difficult to obtain the significant turbidity removal efficiency from the sewage water because of the complex nature of the sewage water. In absorption based methods, it is desirable to have knowledge of the process variables and their influence on absorption capacity to maximise removal efficiency of the contaminants in pre-decided absorbents. The conventional approach for optimisation of process variables involves many experiments to be performed, which otherwise would be expensive and time- consuming. Moreover, it does not reveal the influence of the interactions between the process variables on the dependent variable (Moghaddam *et al.*, 2011).

Response surface methodology (RSM) has been applied to optimise and evaluate interactive effects of independent factors in numerous chemical and biochemical processes. Recently, several studies describe the use of RSM in various fields such as in biochemistry for fermentation medium optimisation in material processing for describing the performance of coated carbide tools and concrete production, pharmaceutical industry for determining influences of parameters on formulation of physical properties on nasal spray and in water treatment for studying the optimisation of the coagulation flocculation processes (Ahmad *et al.*, 2005). The application of RSM technique on optimising the turbidity removal has been envisage their study. In the present study, the investigation propose to use an sewage treatment plant which is modified phytorid based sewage treatment plant to enhance pollutant removal by physical, chemical and biological treatment. Phytorid bed is a scientifically developed, sustainable constructed wet land treatment methodology for domestic waste water. Recently, much attention has been paid to phytorid sewage treatment because of the 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, 2010). The objective of the present study was to investigate the turbidity removal through sewage treatment plant and to optimum conditions for an efficient turbidity removal in batch experiment. The Box-Behnken design has been applied in the optimisation of experiments using RSM to understand the effect of various operating parameters and their interactions on turbidity removal. The optimum values of the parameters have been determined for NO absorption.

■ METHODOLOGY

Details of the treatment plant :

The average flow rate of sewage water in Nag river was 426 m^3 hr^{-1}. The scientific study to convert sewage water into water resource for irrigating the agricultural crops and gardening was proposed. It was decided to undertake a pilot project as a novel model in collaboration with NEERI technology and the treatment plant was constructed at Maharajbag campus of Agriculture College, Nagpur. The plant was designed considering the capacity 100 m^3/d of treated water. As the sewage water flow was 426 m^3 hr^{-1} it was not possible to construct the phytorid constructed wet land directly across the flowing river which was requiring huge amount of funding and space. Therefore to make the technology assessable as suggested by (Massuod *et al.*, 2009) according to the water requirement, the intake well was designed and constructed at the bank of the river which was provided with the screen to avoid the entry of garbage material in the intake well. The pump was selected for lifting the raw sewage water as per designed capacity of the treatment plant. The uniform gradient was provided to the plant to flow the water from inlet through screening chambers and filter beds to the storage tank.

Design of phytorid treatment plant :

Original design capacity of the phytorid sewage treatment plant is 100 m^3d^{-1} however to optimize the hydraulic loading for best purification efficiency, the loading was made in the range of 50 to 150 m^3d^{-1}.The surface response modeling with Box-Behenken experimental design which is widely used for controlling the effects of parameters in any processes was used for the pre-treatment and optimization. Its usage decreases number of experiments, using time and material resources. Furthermore, the analysis performed on the results is easily realized and experimental errors are minimized. Statistical methods measures the effects of change in operating variables and their mutual interactions on process through experimental design way.

Response surface methodology :

RSM is a collection of mathematical and statistical techniques that are useful for developing, improving and optimising processes and can be used to evaluate the relative significance of several parameters and their effects even in the presence of complex interactions. RSM involves the following advantages: (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). The Box–Behnken design optimises the number of experiments to be carried out to ascertain the possible interactions between the parameters studied and their effects on the absorption of NO. Box–Behnken design is a spherical, revolving design; it consists of a central point and the middle points of the edges of the cube circumscribed on the sphere (Aslan and Cebeci, 2007).

Experimental design for absorption studies :

In order to obtain the optimum condition for turbidity removal, three independent parameters were selected based on the literature available. These are presented in Table 1. The operating ranges for hydraulic loading *i.e.* flow (X_1), dilution (X_2) and spatial length (X_3) were determined by an iterative method. Initially a few preliminary experiments were carried out using the range of variables from 50-150 m^3d^{-1}, 10 - 80m per cent and 16 -100 per cent for X_1, X_2 and X_3, respectively. The final range of parameters was determined from analysis of the data by plotting contour graphs indicating maxima and minima on the entire range. The relationship between the parameters and response were determined using Box-Behnken design under RSM. In this study, the experimental plan consisted of 30 trials, and the independent variables were studied at three different levels, low (-1), medium (0) and high (+1). A Box-Behnken experimental design has the advantage of requiring fewer experiments (15batches) than that would require more in a full factorial design. 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. The Box-Behnken design has good performance with less error. The percentage of turbidity removal is taken as a response (Y) of the experimental design.

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 :

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

where, Y is the response and $x_1, x_2, \ldots, xk$ are the coded independent variables, βi, βj and βij are the linear, quadratic and interaction co-efficients, respectively. β_0 and ε are the constant and the random error, respectively.

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), co-efficient of variation (CV), correlation co-efficient (R^2), adjusted correlation co-efficient (R^2adj), sum of squares (SS), mean sum of squares (MSS), Mallow's Cp statistic test to reflect the statistical significance of the quadratic model. The Design-Expert (trial version 8.0.5, Stat-Ease Inc., USA) software package was used for regression analysis of experimental data, and to plot response surface.

■ RESULTS AND DISCUSSION

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 $m^3\ d^{-1}$, dilution (Initial concentration of sewage) was kept between 10 to 80 per cent and the spatial length was varied between 16 to 100 per cent (Table 1). Experiments were performed in triplicate and repeated at least three times to observe the reproducibility. Minitab 16 free trial version software package for regression and graphical analysis of the data obtained. In all calculation, spreadsheets of Microsoft Excel 2007 were used as ODBC.

(Open Database Connectivity) data source running under Windows. The tabulated value of F statistic corresponding to df was obtained at desired probability level (*i.e.* 0.05 significance level or 95 % confidence).

Statistical evaluation :

Table 2 contains the results of turbidity along with experimental conditions .By applying the multiple regression analysis on the design matrix obtained responses given in Table 2, established approximate function for pollutant concentration removal applicable for treatment plantin the present study in uncoded form is given in following equation (Bhanarkar *et al.*, 2011).

$$\mathbf{Y=58.2873 - 0.423702X_1 - 6 - 0.605935X_2 - 0.455168X_3 + 0.00143583X_{1\ 2} + 0.002134357X_{2\ 2} + 0.000943641\ X_{32} + 0.000464286X_1X_2 + 0.00144643X_1X_3 + 0.00340986X_2X_3} \quad \text{.... (2)}$$

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.

The ANOVA was conducted as the analysis of the variance is considered to be essential to test the significance of the developed model (Sen and Swaminathan, 2004).The summary of ANOVA of the regression model presented in Table 3 indicates that the model equation can adequately be used to describe the concentration removal of turbidity under a wide range of operating conditions.

F-value of 84.24 which was found to be greater than the tabulated value (F_{tab}=4.1) implies that the model is significant for removal of the TDS. For the fixed model, adequate precision can be ensured with a signal to noise ratio greater than 4. An adequate precision of 20.04 suggests the ability of model to precisely navigate through the design space. The low probability value (p-model<F= 0.000 *i.e.* below 0.0001) less than 0.05 indicates quadratic model is highly significant.

The goodness of fit of the model was checked by calculating the regression co-efficient (R^2). A fairly high value of R^2 (97.43 %) suggests that most of the data variation was explained by the regression model. Moreover, a closely high value of the adjusted regression co-efficient (R^2adj = 96.27%) indicates the capability of the developed model to satisfactorily describe the system behaviour within the studied range of operating parameters, as similarly earlier reported by Can *et al*. (2006) and Zhang *et al.* (2010) (Table 3). According to the literature, R^2 adj corrects R^2 for the sample size and the number of terms in the model; e.g. many terms in the model and small sample size might cause that R^2 adj << R^2, which was not obtained in our study. A similar pattern has been reported by others for the second-order RSM experiments based on Box-Benhken (Khajeh, 2011) and central composite (Liu *et al.*, 2004) designs. Further, a relatively low value of the co-efficient of variation (CV=13.5%) indicates good precision and reliability of the conducted experiments as similar to earlier reported by Ahmad *et al.* (2005).

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

The normal probability of the residuals depicted in 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

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

Table 2 : Box-Behnken experimental design matrix with variable and pollutant removal

Run order	Coded variable			Uncoded variable			Response turbity
	X_1	X_2	X_3	Flow (m^3/day)	Dilution (%)	Spatial (%)	
1.	+	-	0	150	10	58	13.5
2.	-	-	0	50	10	58	19
3.	+	0	-	150	45	16	5
4.	0	+	-	100	80	16	0
5.	-	+	0	50	80	58	4
6.	0	-	+	100	10	100	5
7.	-	0	-	50	45	16	15
8.	0	0	0	100	45	58	4
9.	0	-	+	100	10	100	6
10.	0	+	+	100	80	100	5
11.	+	-	0	150	10	58	14.8
12.	-	0	-	50	45	16	15.2
13.	0	0	0	100	45	58	4.2
14.	+	0	-	150	45	16	5.8
15.	0	0	0	100	45	58	2.5
16.	0	-	-	100	10	16	21
17.	0	0	0	100	45	58	2
18.	0	0	0	100	45	58	4
19.	-	-	0	50	10	58	17
20.	-	+	0	50	80	58	3.2
21.	+	0	+	150	45	100	8.9
22.	0	+	+	100	80	100	4.1
23.	0	0	0	100	45	58	4.2
24.	-	0	+	50	45	100	6
25.	0	-	-	100	10	16	21
26.	-	0	+	50	45	100	7
27.	+	0	+	150	45	100	8
28.	+	+	0	150	80	58	4
29.	0	+	-	100	80	16	0
30.	0	+	0	100	80	58	2

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

Table 3 : Analysis of variance (ANOVA) of the response surface quadratic model for prediction of turbidity removal efficiency

Factor (Coded)	DF	Sum of squares	Mean square	F –value	p -value	Remark
Model	9	1095.39	121.710	84.24	0.000	Significant
Flow (m^3/d)	1	40.32	40.322	27.91	0.000	Significant
Dilution (%)	1	564.06	564.062	390.41	0.000	Significant
Lenght (%)	1	64.00	64.000	44.30	0.000	Significant
Flow (m^3/d) *Flow(m^3/d)	1	80.52	95.152	65.86	0.000	Significant
Dilution (%) *Dilution (%)	1	45.93	50.482	34.94	0.000	Significant
Lenght (%)*Lenght (%)	1	20.46	20.462	14.16	0.001	Significant
Flow(m^3/d)*Dilution (%)	1	5.28	5.281	3.66	0.070	
Flow(m^3/d)*Lenght (%)	1	73.81	73.811	51.09	0.000	Significant
Dilution (%)*Lenght (%)	1	201.00	201.001	139.12	0.000	Significant
Residual error	20	28.90	1.445			
Lack-of-Fit	3	15.55	5.184	6.60	0.004	Significant
Pure error	17	13.34	0.785			
Total	29	1124.29				

DF- degree of freedom MSSe = 1.445 SSe = 28.90
R-Sq = 97.43% R-Sq(pred) = 93.89% R-Sq (adj) = 96.27%

that none of the individual residual exceeded the value twice of the square root of the error variance. Similar findings were earlier reported by Sen and Swaminathan (2004).

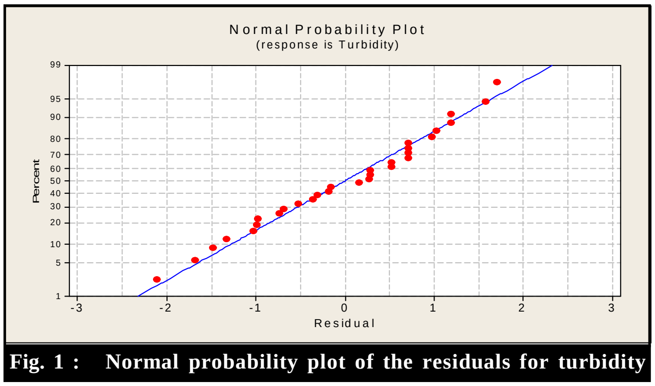

Fig. 1 : Normal probability plot of the residuals for turbidity

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

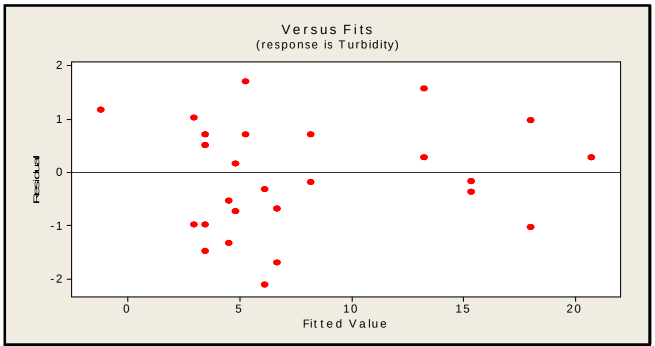

Fig. 2 : Internally studentied residuals vs. predicted value plot for turbidity

As evident from Fig. 3 the distribution graph of turbidity slightly skewed with for large value. Although with this sample size it was probably having very slight departure from the normality and homogeneity. The histogram was distributed in the residual value of - 2.4 to + 1.5. The maximum height of the graph depicting the maximum frequency for width of residual 0.5 equal to 9 and whereas minimum frequency observed for (–2.0) and it was 1 and inferring the response transformation was appropriate.

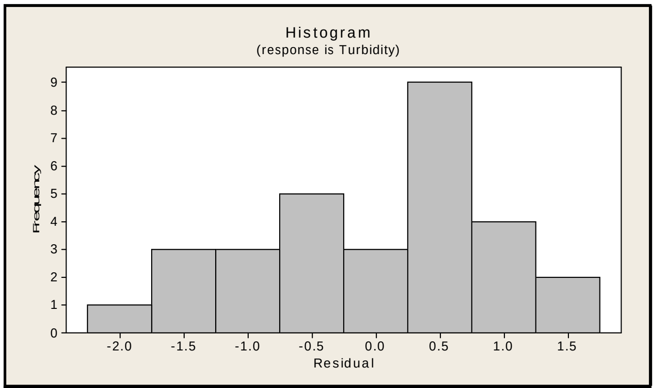

Fig. 3 : Internally studentied frequency vs. residuals value plot for turbidity

The plots of residuals versus the order of the data presented in Fig. 4 revealed that all the residual values were lying within the range of -2 and +2. They do not exhibit any serious departures from the homogeneity and the normal. The large variation were recorded for the observation order no. 3 with flow 150 m^3 d^{-1} and length 16 per cent whereas minimum variation was observed for observation order nos. 12 with flow 50 m^3 d^{-1} showing the model successful in capturing the correlation between the influencing parameter of the BOD removal process.

Effect of model component and their interaction on pollutant removal :

The result of student t-test and p-value conducted to

Table 4 : Multiple regression result and significance of the quadratic model for turbidity

Factor coded	Co-efficient	Standard error	Effect	t ratio	PC (%)
Intercept	3.4833	0.4907	6.9666	–	–
Flow(m^3/d)	-1.5875	0.3005	-3.175	-10.5657	3.68
Dilution (%)	-5.9375	0.3005	-11.875	-39.5175	51.49
Lenght (%)	-2.0000	0.3005	-4.000	-13.3111	5.84
Flow(m^3/d) *Flow(m^3/d)	3.5896	0.4423	7.1792	16.23152	7.35
Dilution (%) *Dilution (%)	2.6146	0.4423	5.2292	11.82274	4.20
Lenght (%) *Lenght (%)	1.6646	0.4423	3.3292	7.527018	1.87
Flow (m^3/d) *Dilution (%)	0.8125	0.4250	1.625	3.823529	0.48
Flow (m^3/d) *Lenght (%)	3.0375	0.4250	6.075	14.29412	6.74
Dilution (%) *Lenght (%)	5.0125	0.4250	10.025	23.58824	18.35

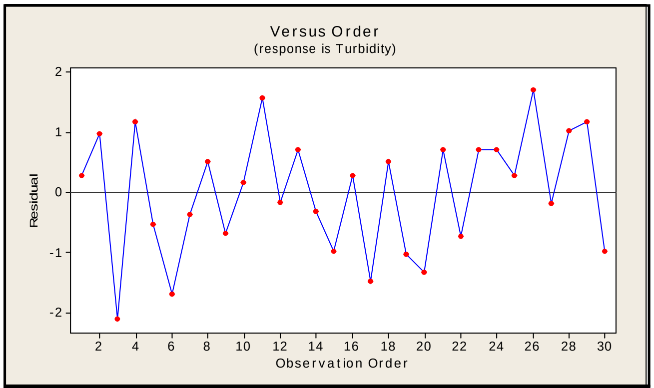

Fig. 4 : Plot between observation orders vs. residuals value plot

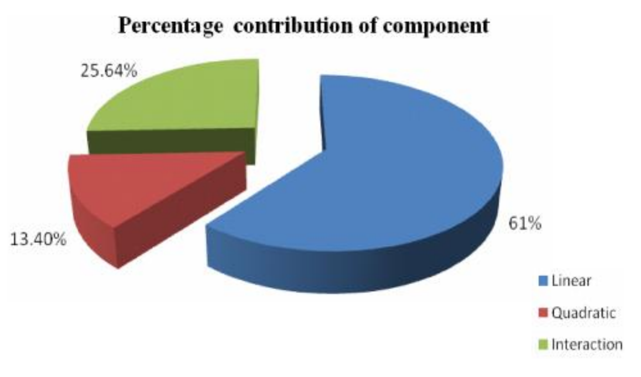

Fig. 5 : Schematic diagram showing percentage contribution of the component for turbidity removal

evaluate the significance of the quadratic model co-efficient 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 co-efficient value for that parameter. The p value is used as tool to check the significance of the co-efficient. The largest the magnitude of t value and smaller the p value, significant is the corresponding parameter in the regression model as reported by Ye ltilmezsoy *et al.* (2009).

Results showed that all the linear and quadratic terms were statistically significant ($p < 0.05$). Similarly all interactive terms were found statistically significant except (flow X_{1*}dilution X_2). Moreover, the first-order main effects of all the three 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) and interaction. The t- and p-value (Table 3 and 4) suggested that the dilution (X_2) and length(X_3) have a direct relationship on the turbidity removal. Dilution (X_2) was found to be the most significant component of the regression model for the present application, whereas, the linear term flow (X_1), quadratic term length and interaction term between flow (X_1) $_*$ dilution (X_2) showed the lowest effect on the turbidity removal.

Table 4 also includes the per cent contribution (PC) of each of the individual terms in the final model computed using the sum of squares (SS) values of the corresponding term. Similar finding were reported by Singh *et al.* (2011). As evident from Table 4, the dilution per cent (X_1) showed the highest level of significance with a contribution of > 51.49 per cent as compared to other components. As depicted in Fig.4 shown the total percentage contribution (TPC) of the possible first order, quadratic and interactive component calculated to Meng *et al.* (2007).

Results presented in Fig.4 revealed that among the calculated TPC values, first-order terms had the highest level of significance with a total contribution of 61 per cent as compared to other TPC values. This was followed by the TPC of quadratic terms with a total contribution of 13.40 per cent.

The TPC of interaction terms showed the lowest level of significance with a total contribution of 25.64 per cent, indicating that the quadratic components showed a little effect in prediction of the turbidity removal efficiency. Hence, TPC values also proved that the first-order independent variables have a direct relationship on the dependent variable (Fig. 5).

Optimization of experimental condition for turbidity removal:

In order to gain better understanding of the influence of the independent variables and their interactions on the dependent variable, 3D response contour plots for the measured responses were drawn based on the quadratic model as suggested by Ye timezsoy *et al.* (2009). Fig. 6 exhibits the 3D response contour plots as the functions of two independent variables keeping other variable fixed at the centre level.

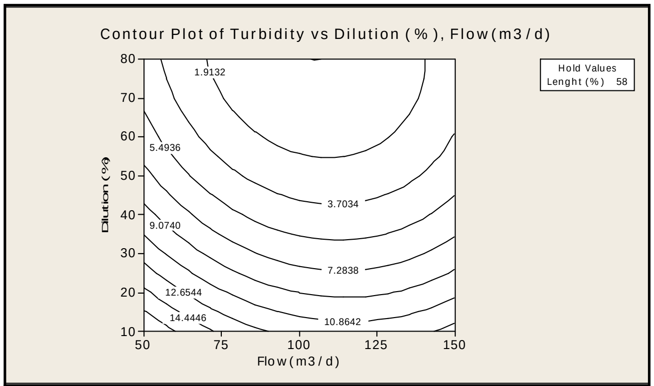

Fig. 6(a): Contour plot showing effect of two independent variables (Length was held at their respective centre level) (a) Dilution (%) and flow (m^3 d^{-1})

It can be seen from Fig. 6(a) that turbidity removal increased with increasing dilution from 10 to 80 per cent whereas turbidity removal slightly increased with increase in flow from 50 m^3 d^{-1} to 100 m^3 d^{-1} and thereafter it was found decreased up to 150 m^3 d^{-1} . This increase in the BOD removal with increase in dilution might be due to addition of the well water having lower value of turbidity. Turbidity removal was found constant with flow from 85 m^3 d^{-1} to 125 m^3 d^{-1}. A significant BOD removal was observed at flow rate 100 m^{3}d^{-1} and dilutions less than 70 per cent.

Fig. 6(b) it is evident that turbidity removal increased with increasing length from 10 to 100 per cent. Considerable turbidity removal can be seen at 80 percentage lengths and 100 m^3 d^{-1}, reason might be due to removal of turbidity during sewage water passing through the phyto plants along the length of the phytobed of treatment plant. A significant value of turbidity was obtained at 100m^3 d^{-1}flow and 80 per cent length. The turbidity removal was slightly increased with 50 m^3 d^{-1} to 100 m^3 d^{-1} flow rate and onward it was removal was observed near about constant with increased in flow rate from100m^3 d^{-1} to higher values. The reason might be higher value of turbidity in sewage water in excess flow than the capacity of the plant. Further, it is evident from the figure plotted at flow 100 m^3 d^{-1} that dilution played an important role in turbidity removal.

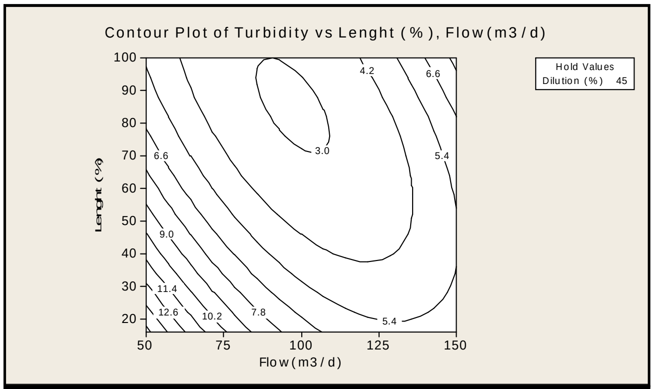

Fig. 6(b): **Contour plot showing effect of two independent variables (Dilution was held at their respective centre level) (b) Length (%) and flow (m^3 d^{-1})**

Fig. 6(c) revealed that turbidity removal increased with increasing length as well as dilution. The range of removal of turbidity was from 20 mg L^{-1} to 7.0 mg L^{-1} along the length whereas with dilution the range of removal of BOD was from 20 mg L^{-1} to 0.0 mg L^{-1}.The removal of turbidity along the length was due physical treatment when sewage water passing along the length of the phytobed of sewage treatment plant. Similarly removal of BOD due to dilution was by addition of fresh water with very low turbidity. Significant removal was observed at 55 per cent length and 73 per cent dilution (Jamwal and Mittal, 2010).

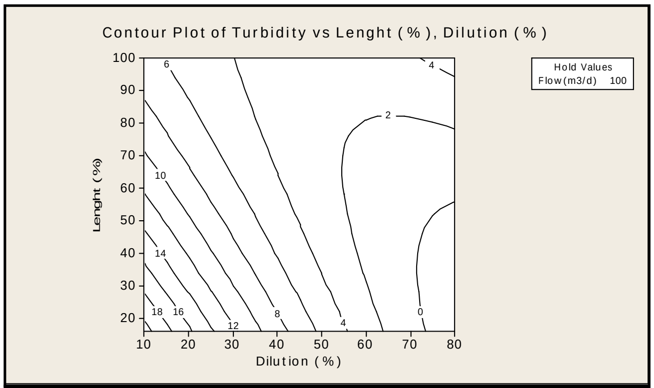

Fig. 6(c): **Contour plot showing effect of two independent variables (Flow was held at their respective centre level) (c) Length (%) and dilution (%)**

Response optimization :

The optimization of turbidity by using the response optimizer was carried out for independent variable for the value of turbidity = 7 as presented in Fig.7. The optimized global solution for the independent variable found was flow =150 m^3 d^{-1}, dilution=65.13 per cent and spatial length=87.64 per cent with composite desirability equal to 1.000 (Arulkumar *et al.*, 2011).

Parameters :

Goal	Lower	Target	Upper	Weight	Import
Turbidity target	1	7	19	1	1

Global solution :

Flow (m^3/d) = 150
Dilution (%) = 65.1332
Length (%) = 87.6499

Predicted responses :

Turbidity = 7.00000, desirability = 1.000000
Composite desirability = 1.000000

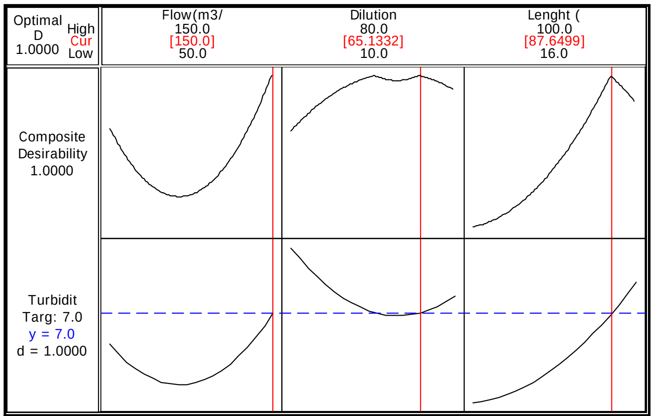

Fig. 7 : **Contour plot showing the optimizing condition of the turbidity : Predicted vs. actual**

The diagnostic plot shown in Fig. 8 indicated the experimental and the predicted turbidity concentration removal values and was used to estimate the adequacy of the regression model. Observed and predicted values of turbidity removal were observed in well agreement. The points cluster around the diagonal line indicated a good fit of the model as earlier reported by Ahmad *et al*. (2005) in optimizing the condition for turbidity parameter.

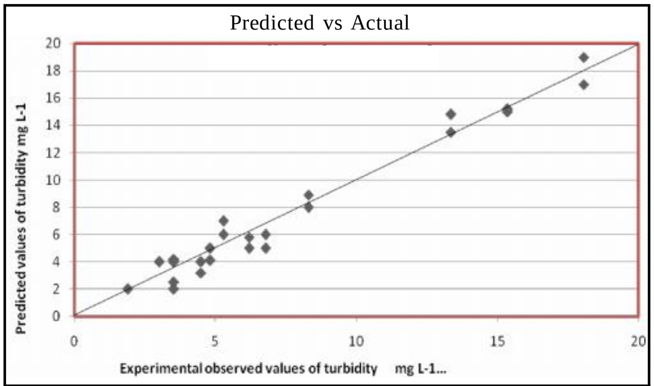

Fig. 8 : Plot showing the experimental observed value versus predicted value of the turbidity

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