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ORIGINAL ARTICLE

Performance of SBR for the treatment of textile dye wastewater: Optimization and kinetic studies

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Abstract In this work, sequential batch reactor (SBR) was employed for the treatment of textile dye wastewater. The performance of four white rot fungi (WRF) viz. *Coriolus versicolor*, *Pleurotus floridanus*, *Ganoderma lucidum* and *Trametes pubescens* was evaluated in pure and mixed combinations in terms of decolorization. From the results it was found that the combination of *Pleurotus floridanus*, *Ganoderma lucidum* and *Trametes pubescens* was best and they were used in the SBR. The process parameters like air flow rate, sludge retention time (SRT) and cycle period were optimized using response surface methodology (RSM). At these optimized conditions, treatment of textile dye wastewater was carried out at various initial dye wastewater concentration and hydraulic retention time. The performance of SBR was analyzed in terms of decolorization, COD reduction and sludge volume index (SVI). From the results it was found that a maximum decolorization and COD reduction of 71.3% and 79.4%, respectively, was achieved in the SBR at an organic loading rate of 0.165 KgCOD/m^3 d. The sludge volume index (SVI) was found to be low in the range of 90–103 mL/g. The kinetic study was carried out using a first order based model and the degradation follows the first order system.

1. Introduction

Dyes are widely used in industries such as textile, paper, tannery etc. During dyeing process in textile industries, large amount of water is consumed and generates substantial amount of wastewater. The unutilized dye up to 15% in the dyeing process was found in the wastewater [1,2]. Dyes present in wastewater affect the human beings, aquatic life and environment [3,4]. Treatment of textile dye industry wastewater is highly complex due to the presence of color, toxicity, BOD, COD, turbidity, TDS, TSS, etc. Physical and/or chemical processes like chemical coagulation/flocculation, ozonation, oxidation, ion exchange, irradiation, precipitation and adsorption are employed for the treatment of dye wastewater [5–7]. But these processes have some drawbacks viz. excess amount of chemical usage, or accumulation of concentrated sludge with obvious disposal problems, expensive plant

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requirements or operational costs, lack of effective color reduction, and sensitivity to a variable wastewater input [8].

Alternatively biological processes has received great attention in recent years for its efficiency and inexpensive. Microorganisms like bacteria, fungi and yeast are widely used for the decolorization of dye wastewater [9]. Among these, white rot fungi (WRF) are capable of degrading synthetic dyes that are able to depolymerize and mineralize lignin because of their low substrate specificity and degrade the wide range of xenobiotic compounds.

Sequential batch reactor (SBR) is a modified activated sludge process used to treat a variety of wastewaters viz.; domestic wastewater, landfill leachate, industrial wastewater, biological phosphorus and nitrogen removal. SBR has the following advantages in a small-scale system: flexibility in operation, low construction and maintenance cost and simultaneous removal of nitrogen and phosphorus. There are several literatures supporting the applicability of this promising reactor in wastewater treatment [10–18].

Response surface methodology (RSM) is a combination of mathematical and statistical techniques used for optimizing the processes and to evaluate the relative significance of several affecting factors even in the presence of complex interactions. RSM is widely used in enzyme production, food technology, environmental biotechnology etc. [19–21]. RSM is also used for the optimization of process conditions [22]. Zinatizadeh et al. [23] employed RSM in SBR for the treatment of dairy wastewater and is the only work available for the application of RSM in SBR. In this study, RSM is applied for the optimization of process variables for the treatment of textile dye wastewater in a SBR. A mixed white rot fungal strains were used to treat the textile dye industry wastewater. The performance of SBR was also studied at various operating conditions and the kinetics of biodegradation was also studied.

2. Materials and methods

2.1. Textile dye industry wastewater

The textile dye industry wastewater was collected from a small scale textile dye industry located at Erode in Tamilnadu, India. The combined wastewater was stored at 5 °C in a freezer. The wastewater was analyzed in the laboratory and it was reported in our earlier article [24].

2.2. White rot fungus (WRF)

The white rot fungi such as *Coriolus versicolor* (MTCC – 138), *Pleurotus floridanus* (MTCC – 6315), *Ganoderma lucidum* (MTCC – 1039) and *Trametes pubescens* – (MTCC – 1813) were used in this work. They were obtained from Microbial Type Culture Collection Centre (MTCC), Chandigarh, India. The strains were maintained on solid medium at 4 °C. The medium composition was given by Sathian [25]. Batch experiments were carried out in 500 ml Erlenmeyer flask at various combinations of these four white rot fungal strains (*Coriolus versicolor*, *Pleurotus floridanus*, *Ganoderma lucidum* and *Trametes pubescens*) with the diluted textile dye wastewater in the ratio 1:2. Experiments were performed at the optimized conditions of pH (6.6), temperature (28 ± 1 °C) and agitation speed (150 rpm). The results obtained were compared and the best combination was selected for SBR system.

2.3. Sequential batch reactor (SBR)

The experimental set up of the SBR was shown in Fig. 1. A laboratory-scale reactor, made up of plexiglass, with a total volume of 3.5 L and working volume of 2 L was used. Tubes were inserted into the reactor to ensure the filling and withdrawal of the effluent using peristaltic pumps. The reactor was supplied with oxygen by fine bubble air diffuser. The mixing inside the reactor was achieved with a mechanical stirrer at the speed of 170 rpm. Each cycle lasted for 24 h: filling – 1 h, reaction – 20 h, settling – 2 h, withdrawal – 0.75 h and idle – 0.25 h. SBR was inoculated with the mixed WRF (*P. floridanus*, *G. lucidum* and *T. pubescens*) from the batch study.

2.4. Reactor inoculation and startup

SBR was filled with the textile dye industry wastewater. The reactor was inoculated with the mixed WRF (*P. floridanus*, *G.lucidum* and *T. pubescens*). Air was supplied at the rate of

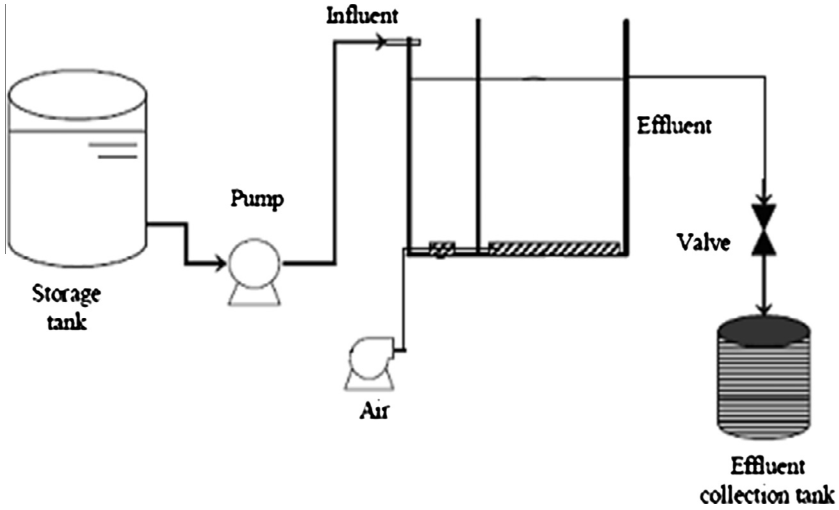

Figure 1 Schematic diagram of sequential batch reactor set up.

10 LPH and pH was maintained at the optimum value of 6.6. Temperature was maintained at 28 ± 1 °C [25]. The set up was left for 10 days with aeration in order to acclimatize the microorganisms. Then the textile dye industry wastewater was pumped into the reactor and air was supplied at the same rate.

2.5. Experimental procedure for SBR

Experiments were performed in SBR, based on the Box-Behnken design (BBD) as shown in Table 1. The hydraulic retention time (HRT) in the reactor was maintained as 5 days. The effect of process variables like, air flow rate (10, 15 and 20 LPH), SRT (10, 15 and 20 d) and cycle period (24, 48 and 72 h) was studied in SBR. These parameters were optimized using RSM. During the 1 h, raw textile dye wastewater was fed into the reactor. The aeration was done for another 20 h (react step: aeration). Aeration was then shut down for 2 h (settle step: sedimentation). After the bio sludge was fully settled, the supernatant had to be removed within 0.75 h (draw step: decant) and the system had to be kept under idle (idle step) for 0.25 h. After that, fresh textile dye wastewater was introduced into the reactor and the above operation was repeated. To control the stable bio sludge concentration in the reactor, the excess bio sludge was removed from the bottom of the reactor, during the idle step. All the experiments were performed using BBD and the decolorization, sludge volume index (SVI) and COD were analyzed for each condition as per standard methods of analysis [26].

At the optimized conditions, experiments were carried out in SBR to study their performance at various organic loading rates (OLR). OLR was varied by changing the influent wastewater concentration (1650 and 2450 mg/L) and HRT (5, 4 and 3 d). The operating conditions were given in Table 2. During the 75 days of operation, decolorization, COD reduction, mixed liquor suspended solids (MLSS) and sludge volume index (SVI) were measured as per standard methods of analysis [26].

Table 2 Operating conditions of SBR.

Substrate concentration (mg COD/L)	Day	HRT (d)	OLR (kg COD/m^3 d)
1650	1–16	5	0.165
	17–24	4	0.210
	25–38	3	0.275
2450	39–52	5	0.245
	53–60	4	0.310
	61–75	3	0.410

3. Results and discussion

3.1. Selection of WRF

The WRF's *C. versicolor*, *G. lucidum*, *P. floridanus* and *T. pubescens* were used for the treatment of textile dye industry wastewater, in pure and mixed form. The results obtained were given in Table 3. From the table it was found that the combination *P. floridanus*, *G. lucidum* and *T. pubescens* yields a maximum decolorization of 87.2%. Hence this combination was selected for the treatment of textile dye industry wastewater in sequential batch reactor. In SBR, all the experiments were carried out at the optimum conditions of pH: 6.6 ± 0.2, temperature: 28 ± 1 °C, agitations speed: 180 ± 5 rpm [25].

3.2. Model fitting and analysis

In a SBR, treatment of textile dye wastewater was carried out using mixed WRF's. Experiments were carried out using BBD and the results obtained were given in Table 1. The experimental results were analyzed through RSM to obtain an empirical model for the responses. The polynomial equation obtained for decolorization, COD reduction and SVI was:

$$\begin{aligned}\%\ \text{Decolourization} = {} & 55.85 + 2.45A + 1.22B - 0.15C \\ & - 1.80AB + 0.053AC - 0.11BC \\ & - 7.26A^2 - 4.39B^2 + 0.081C^2 \end{aligned} \quad (1)$$

Table 1 Experimental and predicted values of decolorization, COD reduction and SVI in SBR.

Run. no.	*A* (LPH)	*B* (d)	*C* (h)	Decolorization (%)		COD reduction (%)		SVI (mL/g)	
				Expt.	Predicted	Expt.	Predicted	Expt.	Predicted
1	20	15	72	51.7	51.48	56.7	56.62	105	105.35
2	15	15	24	56.8	56.11	60.9	59.22	84	80.35
3	15	15	48	55.8	55.87	58.9	58.96	81	82.50
4	20	15	24	51.1	51.21	53.4	53.69	86	88.25
5	15	10	24	50.2	50.35	52.5	53.20	91	88.24
6	10	15	24	46.1	46.42	49.4	49.77	99	100.91
7	15	15	48	55.8	55.87	58.7	58.96	81	82.51
8	10	20	48	44.7	44.59	45.7	45.72	105	101.54
9	20	10	48	47.3	47.33	50.6	50.29	96	97.20
10	20	20	48	45.9	45.97	48.7	48.79	101	97.19
11	15	20	24	52.9	53.01	54.4	54.69	85	87.25
12	15	15	72	55.9	56.16	58.9	59.38	104	98.64
13	15	15	48	55.8	55.87	58.7	58.96	81	82.50
14	15	20	72	52.7	52.65	55.9	55.48	92	97.01
15	10	10	48	38.9	38.72	40.4	40.01	119	120.55

A – air flow rate; *B* – sludge retention time; *C* – cycle period.

Table 3 Performance of WRF's in pure and mixed form at their optimum conditions.

Microorganism	Decolorization (%)
Coriolus versicolor (CV)	64.4
Ganoderma lucidum (GL)	71.2
Pleurotus floridanus (PF)	81.4
Trametes pubescens (TP)	77.8
CV + GL	72.0
CV + PF	82.2
CV + TP	78.7
GL + PF	83.4
GL + TP	80.5
PF + TP	84.3
CV + GL + PF	84.0
CV + GL + TP	80.9
CV + PF + TP	84.6
GL + PF + TP	87.2
CV + GL + PF + TP	87.1

$$\begin{aligned}\%\ \text{COD reduction} = {} & 58.97 + 2.65A + 0.90B - 0.15C \\ & - 1.80AB + 0.69AC + 0.15BC \\ & - 7.47A^2 - 5.25B^2 + 0.094C^2 \end{aligned} \tag{2}$$

$$\begin{aligned}\text{SVI} = {} & 79.20 - 6.63A - 2.63B + 0.90C + 4.75AB \\ & - 0.33AC - 2.16BC + 14.49A^2 + 7.65B^2 + 1.85C^2 \end{aligned} \tag{3}$$

where A, B and C were the coded values of the test variables, air flow rate (LPH), SRT (d) and cycle period (h), respectively.

The results were analyzed by using ANOVA i.e., Analysis of Variance and were given in Table 4. The ANOVA of the quadratic regression model indicates the model to be significant. Model F-value was calculated as a ratio of mean square regression and mean square residual. The P values were used as a tool to check the significance of each of the coefficients, which in turn were necessary to understand the pattern of the mutual interactions between the test variables. The F value and the corresponding P values were given in Table 4. The model F-value for decolorization, COD reduction and SVI implied that the model was significant. Model P value (Prob > F) was very low (0.0001) for all the three responses. This reiterates that the model was significant. The smaller the magnitude of the P, the more significant was the corresponding coefficient. Values of P less than 0.05 indicate the model terms were significant. The P values suggest that, among the test variables used in the study, the linear, square and interactive effect of air flow rate and SRT was significant process variables for decolorization. The terms A, AB, A^2, B^2 and C^2 were significant model terms for COD reduction and A, B, AB, AC, A^2, B^2 were significant terms for SVI.

The predicted R^2 value for the three responses was in reasonable agreement with the adjusted R^2 values. Adequate precision is the measure of the signal to noise ratio and its ratio greater than 4 was desirable. In the present study the ratio was greater than 4 for all the cases, which indicates an adequate signal. The coefficient of determination, R^2 value is always between 0 and 1, and a value >0.90 indicates aptness of the model. For a good statistical model, R^2 value should be close to 1.0. In this study, the fit of the model is also expressed by R^2, which was found to be greater than 0.94, for the three responses. This implies that the prediction of experimental data was quite satisfactory. The coefficient of variation (CV) indicates the degree of precision with which the treatments are compared. Usually, the higher the value of the CV is, the lower the reliability of the experiment. Here a lower value of CV (<4) for the three responses indicates greater reliability of the experiments performed.

The response surface and contour plots were generated for different interactions of any two independent variables, while holding the value of the other variables as constant. Such three dimensional surfaces give accurate geometrical representation and provide useful information about the behavior of the system within the experimental design. The optimization of process variables was aimed at finding the levels of independent variables, which would give maximum percentage decolorization and COD reduction. The 3D plots for the treatment of textile dye wastewater in SBR were shown in Figs. 2–7. The nature of the response surface curves shows the interaction be-

Table 4 ANOVA for the treatment of textile dye wastewater in SBR.

Source	Decolorization		COD reduction		SVI	
	F	$P > F$	F	$P > F$	F	$P > F$
Model	446.17	< 0.0001	14.40	0.0005	104.60	< 0.0001
A	290.01	< 0.0001	14.56	0.0051	66.42	< 0.0001
B	72.50	< 0.0001	2.29	0.1690	7.66	0.0244
C	2.54	0.1497	0.67	0.4362	0.50	0.5008
AB	117.40	< 0.0001	5.61	0.0453	22.98	0.0014
AC	0.21	0.6580	0.056	0.8191	7.03	0.0292
BC	0.85	0.3842	2.44	0.1572	0.35	0.5693
A^2	1587.77	< 0.0001	43.43	0.0002	329.08	< 0.0001
B^2	581.22	< 0.0001	12.12	0.0083	162.71	< 0.0001
C^2	3.22	0.1103	11.64	0.0092	0.86	0.3796
Std. deviation	0.33		4.01		0.75	
R^2	0.9980		0.9419		0.9916	
Adj R^2	0.9958		0.9828		0.9821	
Pred R^2	0.9622		0.8764		0.8329	
CV, %	0.64		3.94		1.38	
Adeq. precision	70.37		13.53		34.62	

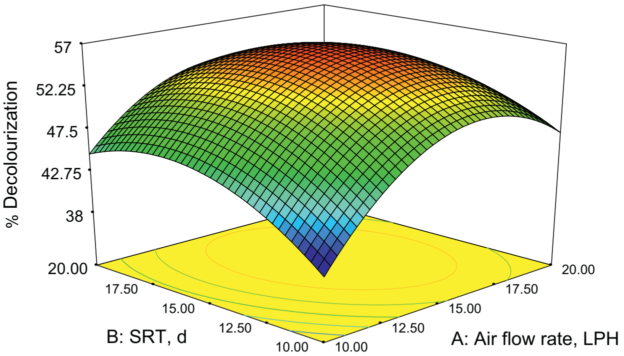

Figure 2 3D plot of the combined effects of air flow rate and SRT on decolorization of textile dye wastewater in SBR.

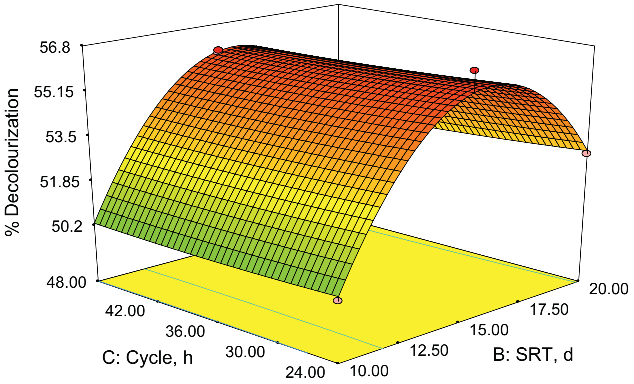

Figure 3 3D plot of the combined effects of SRT and cycle period on decolorization of textile dye wastewater in SBR.

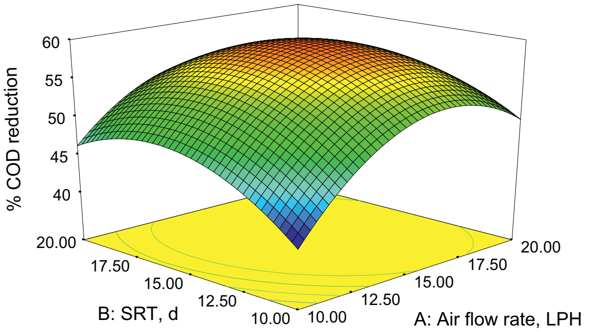

Figure 4 3D plot of the combined effects of air flow rate and SRT on COD reduction of textile dye wastewater in SBR.

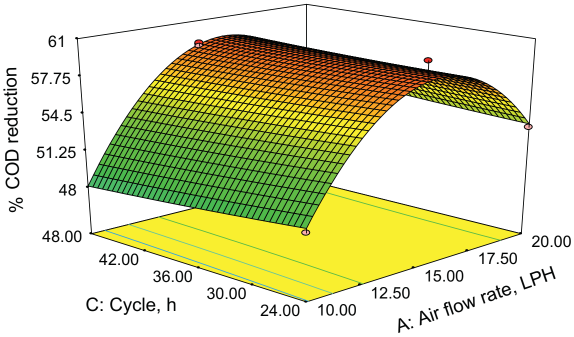

Figure 5 3D plot of the combined effects of air flow rate and cycle period on COD reduction of textile dye wastewater in SBR.

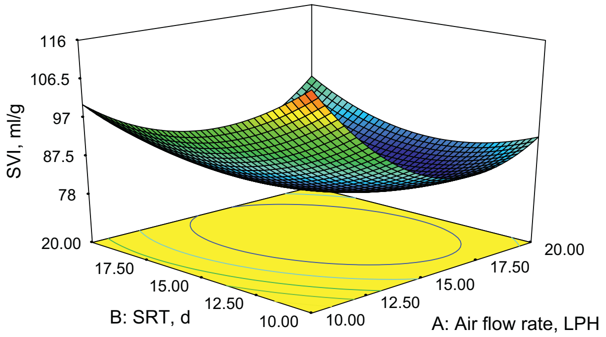

Figure 6 3D plot of the combined effects of air flow rate and SRT on SVI of textile dye wastewater in SBR.

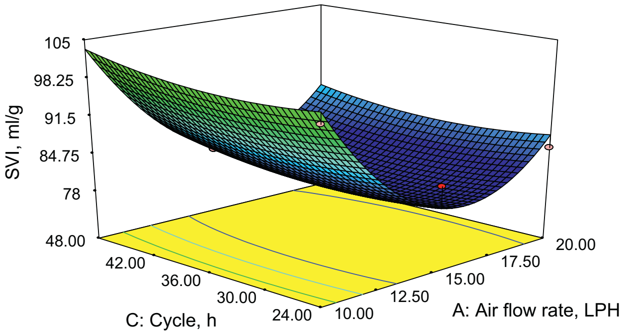

Figure 7 3D plot of the combined effects of air flow rate and cycle period on SVI of textile dye wastewater in SBR.

tween the variables. The elliptical shape of the curve indicates good interaction between the two variables and circular shape indicates no interaction between the variables. From the figures, it is observed that the elliptical nature of the contour in all the graphs depicts the mutual interactions of all the variables. There was a relative significant interaction between every two variables, and there was a maximum predicted decolorization and COD reduction as indicated by the surface confined in the smallest ellipse in the contour diagrams.

3.3. Effect of variables on treatment of textile dye wastewater in SBR

Figs. 2 and 3 show the 3D plots for the decolorization of textile dye wastewater in SBR. Fig. 2 shows the decolorization as a function of air flow rate and SRT. From the figure it was observed that, as the air flow rate increased the decolorization was increased. It should be noted that higher air flow rate above 15.9 LPH decreases the decolorization. At lower air flow rates, the intimate contact between microbes and air molecule was good. But at higher flow rates, due to decrease in the retention time of air, the contact between air and microbes gets reduced. Hence the percentage decolorization decreases at higher flow rates. Fig. 3 showed that an increase in SRT (up to 15 d) yielded an increase in the % decolorization while increase in the cycle period did not have significant effect on the decolorization. At higher SRT's, the accumulation of inorganic salts reduces the activity of the microbes. Hence a decrease in decolorization was observed at longer SRT's. Similar profiles were obtained for COD reduction and were shown in Figs. 4 and 5. These are in agreement with the results obtained by Lourenco et al. [27].

Many researchers consider SVI as the best parameter for characterizing sludge settling properties. It was also a good indicator of sludge bulking. In general, SVI can vary from 30 to 400 mL/g. But a value lesser than 150 mL/g indicates good settling property of the sludge and above this value it was termed as bulking sludge [28]. A proper SVI value, especially below 100 mL/g, was of major importance in the activated sludge systems [29]. The SVI values obtained in this study (81–119 mL/g) were low compared to the results reported by other authors [23,28,30], demonstrating that the SBR can be applied to textile dye wastewater treatment. As noted in Figs. 6 and 7, a reverse impact of increasing airflow rate on SVI was observed. When the air flow rate was increased from 10 LPH to 16 LPH, SVI decreased. Further increase in air flow rate increases SVI. This may be due to the breakdown of sludge's at higher air flow rate. In Fig. 6 and 7, an increase in SRT (from 10 d to 16 d) caused decrease in the SVI value, while at higher SRT (from 17 d to 20 d), the SVI increases. The variable cycle period had no effect on SVI value. This was clearly depicted in Fig. 7.

The perturbation plot shows the comparative effects of the variables on the response. A steep curvature in air flow rate, 'A' curve, shows that decolorization was very sensitive to this factor. The comparatively semi-flat 'B' curve shows less sensitivity of the decolorization to alter with respect to a change in air flow rate. The cycle period have no major impact in the treatment process when compared to air flow rate and SRT.

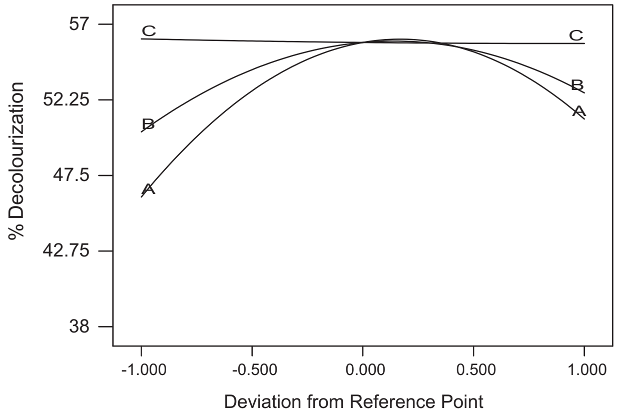

Figure 8 Perturbation plot for decolorization of textile dye wastewater in SBR.

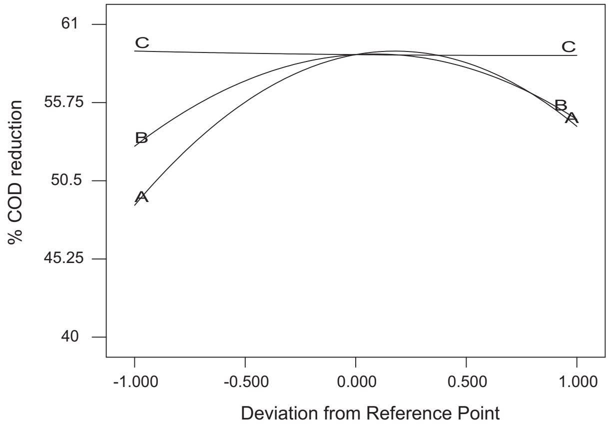

Figure 9 Perturbation plot for COD reduction of textile dye wastewater in SBR.

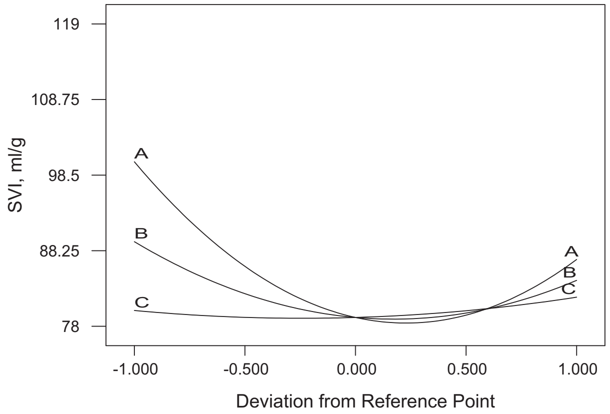

Figure 10 Perturbation plot for SVI of textile dye wastewater in SBR.

It was clear from the perturbation plot (Fig. 8) that the most significant factor on the response was air flow rate. Similar profiles were observed for %COD reduction (Fig. 9). From the perturbation plot (Fig. 10), the most significant factor for SVI was air flow rate. Increase in the air flow rate (up to 16.9 LPH) resulted in decrease in SVI. Although SRT did less significant effect on the SVI in the ranges between 10 and 16 d, a high value of the SRT (20 d) causes an increase in the SVI. In this study, perturbation plot confirmed that the cycle period had no effect on SVI.

The polynomial regression equation obtained was solved using the sequential quadratic programming in MATLAB 7. The optimum values for the maximum percentage of decolorization were air flow rate: 15.9 LPH, SRT: 15 days and cycle period: 24 h. At these optimized conditions, the maximum decolorization and COD reduction was calculated to be 57.7% and 63%, respectively.

3.4. Performance of SBR at various OLR

At the optimum conditions of process variables, SBR was operated at an initial substrate concentration of approximately

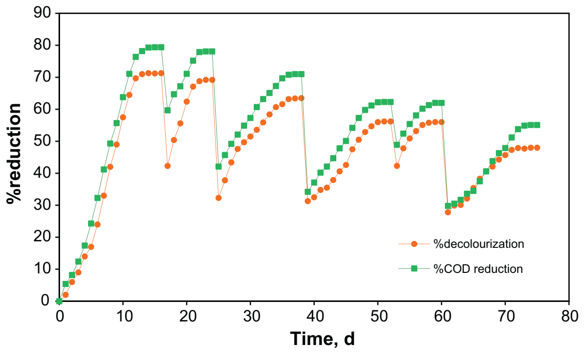

Figure 11 Performance of SBR at various operating conditions.

1650 mg COD/L and the results obtained were shown in Fig. 11. At the initial stage, the HRT of the reactor was maintained at 5 days with an organic loading rate of 0.165 kg COD/m^3d. At this stage, the decolorization was found to be low due to the fact that microbes need longer time for acclimatization. The reactor reached steady state within sixteen days of operation. It was observed that a maximum decolorization of 71.3% and COD reduction of 79.4% was obtained. The effect of organic loading rate (OLR) was investigated by varying HRT while maintaining the concentration of the influent constant. Organic loading rate was increased from 0.165 kg COD/m^3d to 0.21 kg COD/m^3d by reducing the HRT from 5 days to 4 days on 17th day. The reactor performance was monitored regularly. The reactor reached steady state within eight days of operation. It was observed that a maximum decolorization of 69.2% and COD reduction of 78.1% was obtained. After reaching the steady state, the organic loading rate was increased from 0.21 kg COD/m^3d to 0.275 kg COD/m^3d by reducing the HRT to 3 days and the performance was observed. From the results it was evident that the decrease in HRT reduces the decolorization significantly. A drop in decolorization occurs and the reactor reaches steady state after fourteen days of operation. At this stage, the maximum decolorization and COD reduction was found to be 63.5% and 71%, respectively.

On 39th day, the inlet concentration was raised to 2450 mg COD/L and the HRT was maintained as 5d and the corresponding OLR was 0.245 kg COD/m^3d. At this OLR, a maximum decolorization and COD reduction of 57.1% and 62.6%, respectively, was achieved. After fourteen days, the OLR was increased to 0.31 kg COD/m^3d by decreasing the HRT to 4 d. The maximum decolorization and COD reduction was 56.0% and 62.1% respectively. On 61st day the OLR was increased to 0.41 kg COD/m^3d. At this OLR, the maximum decolorization and COD reduction was found to be 48.0% and 55.2% respectively.

The results obtained in the SBR were summarized in Table 5. Although there was an instantaneous increase in the organic loading rate while decreasing the HRT, a low effluent COD level was recorded in a short period of time. With decrease in HRT, the percentage COD reduction was also found to decrease. However a significant drop in reduction of maximum decolorization and COD reduction occurs for the HRT between 4 days and 3 days. It was also seen that there was no significant improvement in the decolorization and COD reduction above 4 days. Similar profile was observed for the decolorization of textile dye wastewater while increasing the OLR by changing the inlet concentration. These results suggest that SBR has an excellent ability to overcome some relatively high disturbance to input organic loading rate variations and were well in agreement with the findings of Kapdan and Oztekin [31]. They carried out experiments in a SBR with textile dye synthetic wastewater and investigated the effect of variation of initial dye concentration and HRT. They also found that with instantaneous decrease in the HRT, decreases the decolorization and COD removal efficiency.

3.5. Sludge volume index (SVI)

The variation of SVI measured in SBR was shown in Fig. 12. Initially the SVI in SBR was 200 mL/g. During the initial period, up to 15 days, sharp fluctuations were observed. This was due to the microbial acclimation to textile dye wastewater. The

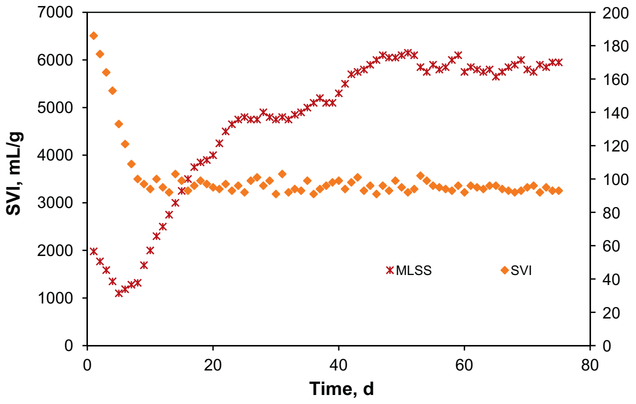

Figure 12 SVI and MLSS variations in SBR during textile dye wastewater treatment.

Table 5 Performance of SBR at various operating conditions for decolorization of textile dye wastewater.

Substrate concentration (mg COD/L)	HRT (d)	OLR (kg COD/m^3 d)	Decolorization (%)	COD reduction (%)
1650	5	0.165	71.3	79.4
	4	0.210	69.2	78.1
	3	0.275	63.5	71.0
2450	5	0.245	57.1	62.6
	4	0.310	56.0	62.1
	3	0.410	48.0	55.2

SVI decreased gradually with the formation of granules. At the end of the experiment, the SVI of the sludge decreased to 92 mL/g, indicating formation mature granular sludge with an excellent settling property. It was observed that after 30 min of settling, the mature granules were well settled, leaving clear supernatant in the reactor. The measured values of SVI in SBR reveal little variability and were mainly in the range from 90 to 103 mL/g. SVI value of more than 100 mL/g, may be due to the aeration system. The SVI value obtained in the SBR was low, and was in agreement with the results reported by other authors. Janczukowicz et al. [30] obtained the SVI of 30–60 mL/g, in a SBR at the wastewater treatment plant in University of Olsztyn. Zinatizadeh et al. [23] observed that sludge of the SVI value of 65–105 during the dairy wastewater treatment in an SBR. Similar results are reported by Ong et al. [32].

3.6. MLSS

The mixed liquor suspended solids was measured in SBR and were shown in Fig. 12. During the initial stage of operation in SBR, the sludge concentration decreased from 2300 mg/L to 1500 mg/L. This may be due to the washout of light sludge. Once the formation of granular sludge began in the reactor, the sludge concentration in SBR increased from 1800 mg/L to 6100 mg/L. But the concentration of sludge decreased after that, because of the larger size of granules limiting the penetration of dissolved oxygen and nutrients, stopping the growth of microorganisms. The large granules broke up to small pieces, which washed out with effluent. By reducing organic loading rate, the sludge concentration in SBR recovered to about 5750 mg/L. There was no correlation between sludge concentration and SVI. These results are well in agreement with others report [33–36].

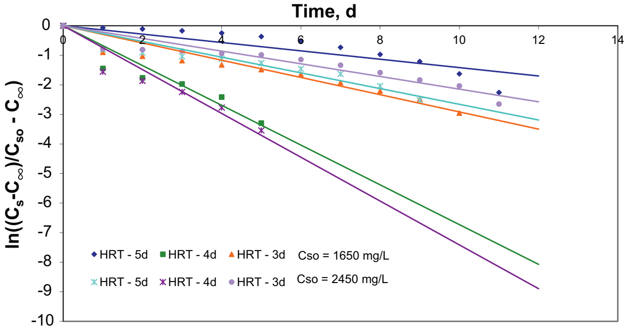

Figure 13 Kinetic plot for the treatment of textile dye wastewater in SBR.

3.7. Kinetic study in SBR

The biodegradation kinetics was studied for the treatment of textile dye wastewater at different initial substrate concentration and various hydraulic retention times. Substrate utilization in the SBR system involves biodegradation of organic matter by the microorganisms in SBR. A first order kinetic expression was often used to describe the biodegradation process [18]:

$$\frac{dC_s}{dt} = -kC_s \tag{4}$$

where C_s is the substrate concentration (mg COD/L), t is the degradation time (min) and k is the biodegradation rate constant.

In this study, a modified first order model was used to simulate the SBR system, which takes into account the quasi steady state [37]:

$$\frac{-d(C_s - C_\infty)}{dt} = k(C_s - C_\infty) \tag{5}$$

By integrating Eq. (5), we get

$$\frac{(C_s - C_\infty)}{C_0 - C_\infty} = e^{-kt} \tag{6}$$

where C_0 was the initial substrate concentration expressed by COD (mg/L), C_∞, the final substrate concentration (mg/L) and k was the pseudo first-order constant (d^{-1}). The degradation rate of organic substrate during react mode in the SBR systems decreased gradually and became nearly constant after certain period of operation. As a result, the final substrate concentration (C_∞) was introduced in the model.

The experimental data obtained from the SBR were represented by the above model. The application of the modified first order model to the COD reduction at different initial substrate concentration and HRT was shown in Fig. 13. By plotting the $\ln(C_s - C_\infty)/(C_0 - C_\infty)$ versus time, a relatively good fit ($R^2 > 0.90$) for all cases indicates that the first-order model (Eq. (6)) provides good correlation of results. The mean k values calculated from the plot shown in Table 6 show that the k value in the SBR was almost similar in the system at a HRT of 5 d and 3 d. At a HRT of 4 d, the maximum k value occurs in the SBR. At high OLR (0.41 kg COD/m^3 d), the k value was found to be low. This may be due to the inhibitory effect of the substrate concentration on microbial activity.

4. Conclusions

Treatment of textile dye wastewater was carried out using pure and various combinations of four WRF's namely *Coriolus ver-*

Table 6 Kinetic constant values for the treatment of textile dye wastewater.

Kinetic constant	Initial substrate concentration					
	1650 mg COD/L			2450 mg COD/L		
	HRT – 5 d	HRT – 4 d	HRT –3 d	HRT – 5 d	HRT – 4 d	HRT – 3 d
k (d^{-1})	0.2495	0.3794	0.3199	0.2948	0.3924	0.2854
R^2	0.9412	0.9121	0.9165	0.9033	0.9015	0.9002

sicolor, *Pleurotus floridanus*, *Ganoderma lucidum* and *Trametes pubescens*. From the results it was found that the combination of *Pleurotus floridanus*, *Ganoderma lucidum* and *Trametes pubescens* gives maximum decolorization. Hence this combination was used in the SBR for the treatment of textile dye wastewater. In SBR, experiments were carried out based on statistical design. The process variables air flow rate, SRT and cycle period were optimized using RSM. At these optimized conditions, the performance of SBR was studied at various OLR's. From the results it was found that a maximum decolorization and COD reduction of 71.3% and 79.4%, respectively, was attained. Low SVI values indicate the better performance of SBR. Kinetic studies show that the degradation follows first order system. From this study, it can be concluded that RSM can be successfully employed in SBR for the treatment of textile dye wastewater.

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