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Statistical Analysis and Optimization of an Aerobic SBR Treating an Industrial Estate Wastewater Using Response Surface Methodology (RSM)

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Abstract: In this study, the performance of an aerobic sequencing batch reactor (SBR) removing carbon and nutrient (N & P) from Faraman's industrial wastewater (FIW) was investigated. This study was performed by varying two significant independent variables viz. aeration time and biomass concentration. The experiments were conducted based on a central composite design (CCD) and analyzed using response surface methodology (RSM). The region of exploration for the process was taken as the area enclosed by aeration time (6-24 h) and mixed liquor volatile suspended solid (MLVSS) concentration (2000-7000 mg/l) boundaries. Seven dependent parameters as the process responses were measured and calculated. Direct and interactive effects of the variables on the responses were described by the models given by RSM. The results showed that the maximum total COD (TCOD) removal of 73.89% was obtained at the highest value of the factors (24 h and 7000 mg/l). The maximum values of total nitrogen (TN) removal efficiency were found to be 36.39%. The low TN removal directed the study to the reduction of oxygen level from 7 to 3 mg/l. The DO reduction with the extended aeration mode resulted in an increase in TN removal while decreased the TCOD, non-biodegradable COD (nbCOD) and BOD removal efficiencies. The oxygen concentration had diminutive effect on phosphorus removal.

Key words: Sequence batch reactor (SBR) % Industrial wastewater treatment % Simultaneous carbon and nutrients removal

INTRODUCTION

The concept of wastewater has become more specific and diverse with advances in industrial development and intensification of urban population. The composition of industrial effluents is characterized by the high structural diversity of constituents and their high concentration levels. Another problem associated with industrial wastewaters is their non-biodegradable chemical oxygen demand (nbCOD) and nutrients content which are not typically considered in conventional treatment processes design [1].

Up to the date, various bioreactors have been examined treating industrial wastewaters including aerobic and anaerobic systems such as up-flow anaerobic sludge bed bioreactor (UASB), continuous stirred-tank reactor (CSTR), sequencing batch reactor (SBR), packed column reactor coupled with activated sludge and rotating biological contactors (RBC) [2-6]. Isik (2004) [7] studied the treatment of cotton textile mill in an UASB coupled with a completely mixed activated sludge system and a range of COD removal between 40-85% at HRT of 120 h was reported. Isik *et al.* [8] also examined the performance of wool acid dying wastewater in the same treatment system and a COD removal between 51-84% at HRT of 17 h was obtained. In another study, treatment of pulp and paper industry wastewater was studied and a COD removal about 85% was obtained at HRT of 12 h [9]. This proves that the wastewater characteristic has a crucial impact on the reactor performance. As industrial zone

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effluents are generated from different industries, the treatment of wastewater is somewhat complicated. However, limited studies are found on the treatment of the mixed effluents from an industrial estate. This study is therefore dealt with the treatment of an industrial zone effluent.

The excessive accumulation of nutrient (N, P) discharge to surface water can pose serious ecological problems that affect the health of aquatic life and consequently that of human and animals [10]. On the other hand, the industrial wastewaters are characterized with a high variation in the stream (max/min>4). In this regard, equalization unit is required in the most industrial wastewater treatment plants [11, 12].

SBR, the so-called fill and draw reactor, separates operating conditions timely in a single reactor. In the SBR, clarifiers and flow equalization tanks are unnecessary and thus, costs of facilities and operation management are much lower than those of continuous flow activated sludge systems. Moreover, the SBR has benefits in that it is easy to change operating conditions, such as cycle times and flow rates [13]. Therefore, the SBR is regarded as an effective system, especially for small wastewater treatment plants.

SBR has been also successfully used in treating wastewaters with excessive amounts of nitrogen and phosphorus. In the SBR process, nutrients removal could be accomplished by three methods: (1) biological phosphorous removal and nitrate denitrification by providing anoxic and anaerobic periods, (2) cyclic aeration (on/off) during the reaction period and (3) operating at low DO concentration to encourage simultaneous nitrification-denitrification (SND) [14]

Response surface methodology (RSM) has an important application in the process design and optimization as well as the improvement of existing design [15]. This methodology is more practical than other method of approaches arises from experimental methodology which includes interactive effects among the variables and, eventually, it depicts the overall effects of the parameters on the process [16]. In the last few years, RSM has been applied to optimize and evaluate interactive effects of independent factors in numerous chemical and biochemical processes [17-19].

This study aimed to evaluate the performance of aerobic SBR treating Faraman's industrial estate wastewater (FIW), Kermanshah-Iran. In this paper, in addition to process analysis, a general factorial design was employed to describe and model variation trends of eight significant responses (total COD (TCOD) removal, BOD removal, nbCOD removal, total nitrogen (TN) removal, total phosphorus (TP) removal, sludge volume index (SVI), settling velocity and effluent turbidity) as a function of two independent variables, aeration time and mixed liquor volatile suspended solid (MLVSS) content of reactor. The applicable improving solution was also proposed and examined.

MATERIAL AND METHODS

Faraman's Industrial Estate Wastewater (FIW): W was collected from a working wastewater treatment plant in Faraman Industrial Estate, Kermanshah, Iran. The samples were stored in a cold room at 4°C. This storage technique had no observable effect on its composition. The FIW characteristics are shown in Table 1.

OD:N:P ratio of the FIW was almost 100:15:2.

Bioreactor Configuration and Operation: The schematic diagram of SBR system is shown in Fig. 1. This system was designed in the form of column for a working volume of 2 L with internal diameter of 8.5 cm and total height of 36 cm. Air was supplied into the reactor by blower and a fine air bubble diffuser from the bottom of the column. The dissolved oxygen (DO) concentration was maintained at about 7 mg/l. The industrial wastewater introduced at the top of reactor. The operational strategy applied to the SBR is described as follows: filling (10 min), mixing with no aeration in order to develop anaerobic condition (40 min), aeration time (depended on the experimental conditions as it was a variable), settling (40 min) and drawing (10 min). In each cycle, about 1.5 L of the supernatant was removed and the same volume of the fresh wastewater was fed. Anaerobic condition was continuously checked by monitoring DO, so that, the level of DO was remained about zero after 20 min (about 40 min under anaerobic condition).

Table 1: Characteristics of Faraman's industrial estate wastewater

Parameters	Unit	Amount
TCOD	(mg/l)	945-1145
SCOD	(mg/l)	478-604
PCOD	(mg/l)	341-601
BOD_U	(mg/l)	388-460
BOD_5	(mg/l)	170-180
nbCOD	(mg/l)	557-682
TN	(mg/l)	135-222
TP	(mg/l)	16-26
TSS	(mg/l)	120-360
pH	-	5.5-7

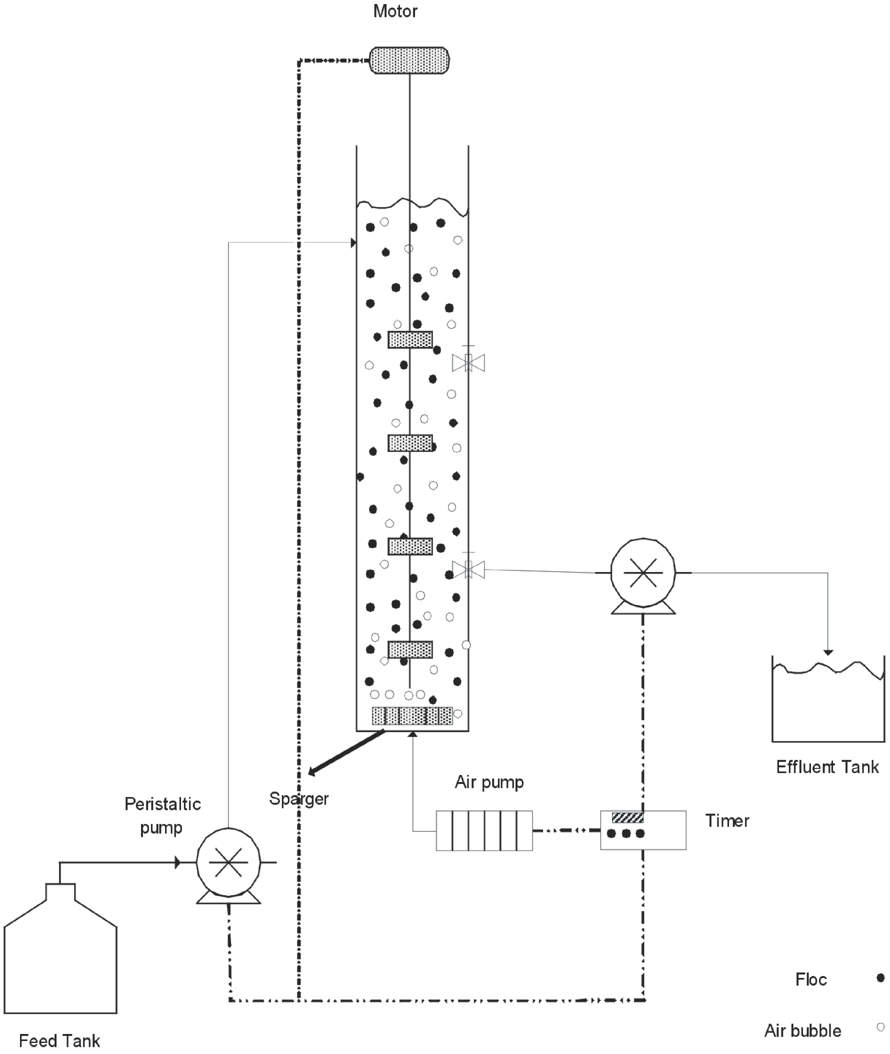

Fig. 1: Experimental set-up

In order to control DO level in the reactor, an air flow meter and a flow adjustment valve were used. The intermittent aeration was supplied by installing a timer on the blower. The process was operated with safety factor (solids retention time/cycle time) greater than 40.

Experimental Design and Mathematical Model: Statistical design of experiments and data analysis was carried out by Design Expert Software (version 7.0). Two independent effective variables, aeration time and MLVSS concentration, were selected in the experiment design. The range and levels of the variables in coded and actual units are given in Table 3. The two operating variables were considered at five levels. In the basis of the factorial design, 13 experiments (including 4 factorial points, 4 axial points, 1 center point and 4 replications of the center point) were designed. TCOD removal, BOD removal, nbCOD removal, TN removal, TP removal, final turbidity, SVI and settling velocity were measured or calculated as response. The experimental conditions and results obtained are shown in Table 4.

The experimental data obtained were used to determine the coefficients of the polynomial model (Eq. 1) as proposed by Khuri and Cornell [20].

$$Y = b_0 + b_i X_i + b_j X_j + b_{ii} X_i^2 + b_{jj} X_j^2 + b_{ij} X_i X_j + ... \quad (1)$$

where, *i* and *j* are the linear and quadratic coefficients, respectively and *ß* is the regression coefficient. P value with 95% confidence level was considered to evaluate the effectiveness of the model terms.

Table 2: Experimental range and levels of the independent variables

	Range and levels				
Variables	-1	-"	0	+"	+1
Aeration time, h	6	11	15	19	24
MLVSS, mg/l	2000	3400	4500	5600	7000

Table 3: Experimental conditions and results

	Variables		Responses							
Run	Factor1 A:MLVSS mg/l	Factor2 B:Aeration time hr	TCOD removal, %	nbCOD removal, %	nbCOD removal, %	TP removal, %	TN removal, %	Final Turb. NTU	SVI ml/g	Settling velocity m/h
1	2000	6	33.01	21.76	53.21	32.67	7.72	131	68	2.26
2	2000	24	40.15	27.47	62.69	51.57	16.26	95.9	72	1.64
3	3400	15	33.23	13.08	78.09	72.3	24.58	47.7	60	1.52
4	4500	11	47.04	28.11	68.39	52.39	21.65	41.1	106	0.08
5	4500	15	53.70	27.55	83.18	61.01	23.50	31	106	0.08
6	4500	19	64.1	63.71	64.77	36.56	20.75	8.08	113	0.05
7	5600	15	56.16	40.89	90.15	56.25	24.97	13.1	110	0.04
8	7000	6	74.64	63.39	92.25	7.84	12.76	11.6	94	0.04
9	7000	24	68.08	55.12	88.36	3.56	38.47	14.6	94	0.04
10	4500	15	57.72	35	62.11	55.41	23.69	32.6	108	0.07
11	4500	15	54.11	38.12	65.25	45.23	22.98	30	100	1.00
12	4500	15	60.26	32.56	63.5	50.69	24.51	20.45	110	0.06
13	4500	15	62.13	30.56	70.56	52.71	23.92	33.21	92	0.06

Table 4: ANOVA results for the equations of the Design Expert 6.0.6 for studied responses

Response	Modified Equations with significant terms	probability	R^2	Adj.R^2	Adeq. precision	S.D	CV	PRESS	Probability for lack of fit
COD removal	53.92+18.03A+1.93B	<0.0011	0.7451	0.6942	11.832	7.03	13.03	810	0.0722
TN removal	$22.94+6.15A+7.88B-4.83B^2+4.25AB$	<0.0003	0.9086	0.8629	16.884	2.68	12.58	2044.88	0.0027
TP removal	$50.57-18.24A-27.44B^2$	<0.0001	0.8556	0.6778	9.988	11.19	27.10	2096.53	0.4520
SVI	$102.98+14.95A-21.83A^2$	<0.0019	0.7995	0.7594	11.271	14.11	18.85	2734.07	1.14
Settling velocity	$0.28-1.02A+0.75A^2$	<0.0003	0.8080	0.7696	11.403	0.38	70.77	2.35	0.6685
Effluent Turbidity	$27.13-49.22A+35.79A^2-10.63B+9.53AB$	<0.0001	0.9656	0.9484	23.809	8.12	20.71	14252.40	0.1208

Analytical Methods: The concentrations of chemical oxygen demand (COD), biological oxygen demand (BOD), total Kjeldahl nitrogen (TKN), nitrate, TN, phosphate, MLVSS, SVI and settling velocity were determined by using standard methods (APHA, 1999) [21]. For COD, a colorimetric method with closed reflux method was developed. Spectrophotometer (DR 5000, Hach, Jenway, USA) at 600 nm was used to measure the absorbance of COD samples. TKN was determined by TKN meter Gerhardt model (Vapodest 10, Germany). DO concentration in wastewater was determined using a DO probe. DO meter was supplied by WTW DO Cell OX 330, electro DO probe, Germany. Turbidity was measured by a turbidity meter model 2100 P (Hach Co. USA).

RESULTS AND DISCUSSION

Process Performance

TCOD Removal: In order to investigate the effects of the studied variables on the TCOD removal efficiency, dependency of this response to the variables was analyzed and modeled. A reduced quadratic model was determined to describe the variation of the TCOD removal as a result of changes in the aeration time and MLVSS content. The ANOVA values for TCOD removal efficiency are shown in Table 4. As presented in the Table, the main effects of the two factors (A and B) are significant model terms. However, the effect of A is much more compared to B (18.03 versus 1.93 as the coefficients in the model).

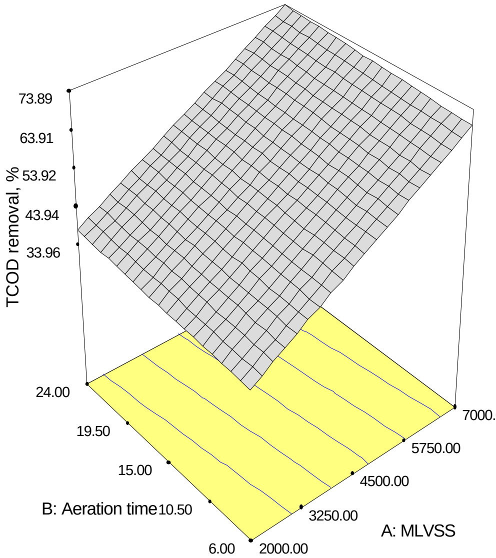

Fig. 2: Response surface plot for TCOD removal efficiency

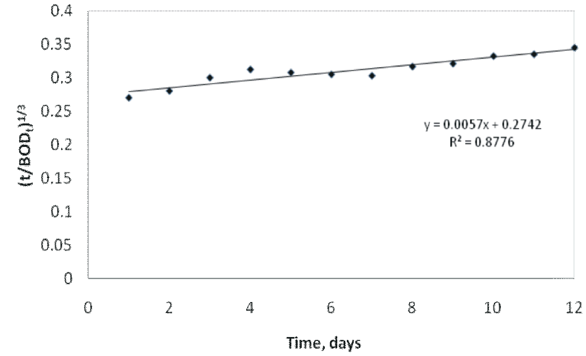

Fig. 3: Calculation of BOD rate constant using Thomas' Graphical Method

Fig. 2 depicts the variation of TCOD removal efficiency as a function of the factors studied. From the Fig, the response linearly increased with an increase in the MLVSS content in the studied range. The maximum obtained value of the response was 73.89% at the highest values of the factors (7000 mg/l and 24 h), indicating a favored condition at a lower food to microorganisms (F/M) ratio provided by higher values of the variables.

BOD and nbCOD Removal: The major problem associated with the biological treatment of industrial wastewater is non-biodegradable fraction of COD (nbCOD) which inhibits the treatment performance of the bioreactors. In order to investigate the bioreactor performance for removing nbCOD, the nbCOD and BOD concentrations at influent and effluent were monitored throughout the experiments. BOD/COD ratio constitutes a good measure of the biodegradability of a wastewater; contaminants with a ratio of BOD_5/COD =0.4 are generally accepted as biodegradable [22]. From a review, the BOD/COD ratio for industrial estate wastewaters is varied from 0.17 to 0.74 [23]. This ratio for FIW was in the range of 0.31-0.5.

With regard to the relatively low BOD/COD ratio, determination of BOD rate constant is of importance. In order to assess the rate of BOD degradation, the BOD rate constant (k) was determined using Thomas graphical method [24]. The linear model based on Thomas graphical method is shown in Fig. 3. The values of BOD rate constant and ultimate BOD were 0.12 day^{-1} and 388 mg/l, respectively. Table 5 represents the biodegradability of BOD contents of various wastewaters [25, 26]. It was found that the biodegradation rate of the FIW's BOD (by comparing BOD rate constant, k) was slower than those obtained for the others, implying longer time required for BOD removal. It must be noted that the low BOD/COD ratio, particularly at the low BOD concentrations, strongly weakens the performance of a biological treatment process.

Fig. 4 represents the BOD and nbCOD removal efficiencies at different conditions. The figure has been drawn according to the experiment numbers as presented in Table 3. From the Fig. as the microorganisms are directly subjected to the substrate, the biodegradable fractions of COD are preferred to be consumed [27]. MLVSS concentration showed a positive effect on nbCOD removal, resulted from a reduction in F/M ratio [28]. As can be seen in the figure, an increase in aeration time caused an increase in nbCOD removal efficiency.

Table 5: BOD constant rates and biodegradable fraction of organic contents of different industrial wastewaters

No.	Type of wastewater	k, d^{-1}	L_0, mg/l	BOD/COD ratio	Reference
1	Food canning wastewater	0.82	6349	0.7	[8]
2	Palm oil mill effluent	0.21	8506	0.3	[27]
3	RAKTA wastewater	0.32	647	0.53	[28]
4	Municipal wastewater	0.22	257	0.64	[28]
5	Faraman's industrial wastewater	0.12	388	0.3-0.5	present study

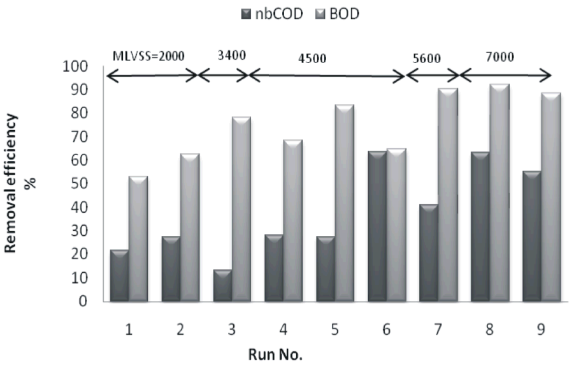

Fig. 4: Removal efficiency of BOD and nbCOD at different studied operational conditions

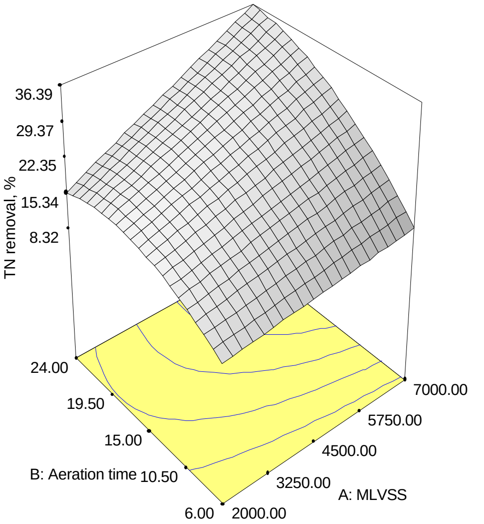

Fig. 5: Response surface plot for TN removal efficiency

Also, a slight decrease in BOD removal was observed at high nbCOD removal (no. 6) which is attributed to the less BOD consumption rate compared to the nbCOD to bCOD conversion rate [29].

Nitrogen Removal: Nitrogen in wastewater can be removed in the form of ammonium through aerobic, autotrophic nitrification followed by anoxic, heterotrophic denitrification. The ANOVA results for TN removal efficiency are presented in Table 4. A reduced quadratic model describes the variation of the TN removal in the studied system. As presented in the Table, the significant model terms were determined to be A, B, B^2 and AB.

Fig. 5 shows the interactive effects of the variables on the response. As can be seen in the Fig. the maximum value of TN removal efficiency was found to be 36.39%. It must be noted that about 30-35% of the TN removed was related to the cell growth. As can be seen in the Fig. simultaneous increase in the factors caused an increase in the response, emphasizing that in addition of MLVSS concentration, aeration time had a remarkable impact on the response. There is an established matter about inverse relationship between MLVSS and DO concentrations, which was also confirmed in this work [30]. It should be highlighted that the DO level of the system at the late hours was more, compared to the conditions with higher organic loads (with a difference about 2-3 mg/l).

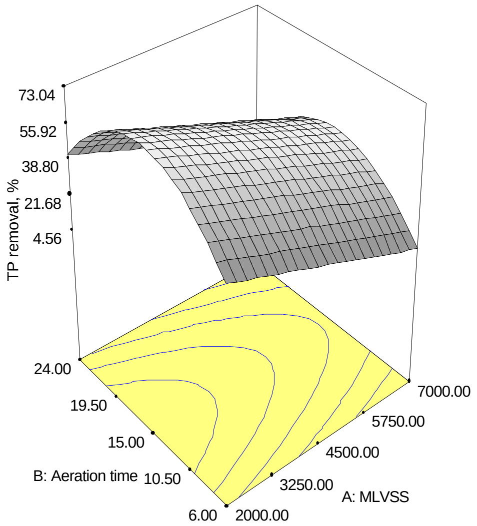

Fig. 6: Response surface plot for TP removal efficiency

Phosphorus Removal: Phosphorus can be removed in biological treatment by repetitive operation of anaerobic and aerobic steps by polyphosphate accumulating bacteria (PAOs) in the form of poly-p. Phosphorus removal was determined as a response in this study. A modified quadratic model described the response variations as a function of the variables. From the ANOVA results presented in Table 4, the main effects of A and second-order of B were significant model terms.

Fig. 6 demonstrates the response versus the variables studied. As can be seen in Fig. 6, an increase in the MLVSS resulted in a decrease in TP removal. It seems that the low BOD loading caused a decrease in TP removal [31]. In this system, an increasing effect of aeration time (from 6 to 15 h) on TP removal efficiency was observed which was due to an increase in phosphorus uptake at a longer aeration time [32]. It must be noted that at aeration times longer than 15 h, the trend was inversed which was attributed to the phosphate accumulating organisms (PAOs) deactivation originated from inadequate poly hydroxy butyrate (PHB).

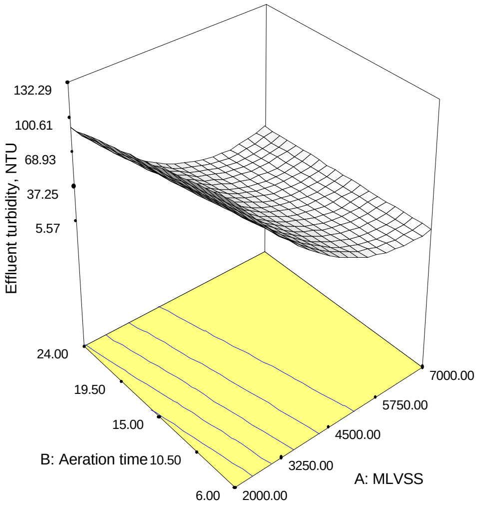

Fig. 7: Response surface plot for effluent turbidity

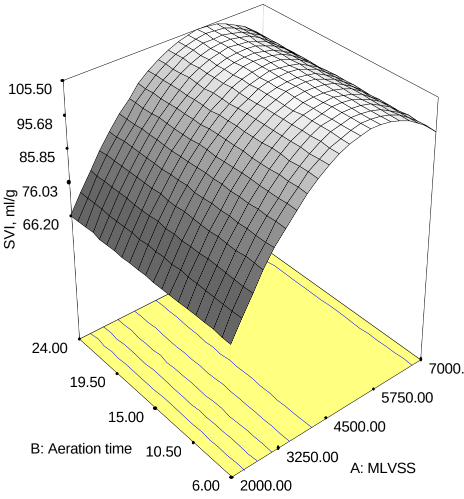

Fig. 8: Response surface plot for SVI

The maximum values of TP removal efficiency were found to be 73.04 %. The relatively high efficiency obtained for TP removal could be attributed to the low initial phosphorus concentration (about 20 mg/l).

Effluent Turbidity: Turbidity, as a process control parameter, indicates the system performance as well as sludge characteristics. From the modified quadratic model describing the response variations presented in Table 4, the MLVSS concentration was found to be the most significant variable. The effects of the variables on the response are shown in Fig. 7. As noted in the Fig. aeration time had no significant impact on the response. Fig. 7 depicts a decrease in the response as a result of an increase in MLVSS concentration implying the ascendancy of sweeping mechanism at higher levels of MLVSS in the form of floc [11]. The findings were approved by the results reported in the literature [33].

Sludge Volume Index (SVI): From the ANOVA results for SVI presented in Table 4, A is the only significant term with the first and second-order effects. Fig. 8 represents the variations of SVI as a function of the variables in the systems. The results showed that SVI increased by increasing MLVSS concentration from 2000 to 5000 mg/l, indicating the decreasing impact of high biomass concentration on the flocs compactness caused by low F/M ratio [30].

Settling Velocity: As the studied system contains a high concentration of suspended solids, both the hindered or zone settling and compression settling usually occur in addition to the discrete (free) and flocculent settling.

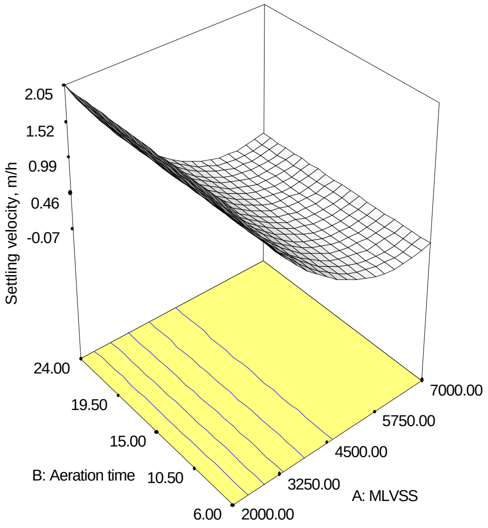

Fig. 9: Response surface plot for settling velocity

The rate of settling in the hindered settling region is a function of the concentration of solids and their characteristics. From the model shown in Table 5, the second-order effect of A is significant model term, indicating that the aeration time in the studied range had no impact. Fig. 9 demonstrates the simultaneous effects of the variables on response. The trend represented in the Fig, conforms to the typical relationship between gravitational solid flux and suspended solids concentration [11].

Improving Strategies for the Process Performance: In order to improve the process performance, removing nutrients as well as minimizing the energy consumption, two solutions were derived from this study. One; operating the system with a lower DO level by reducing

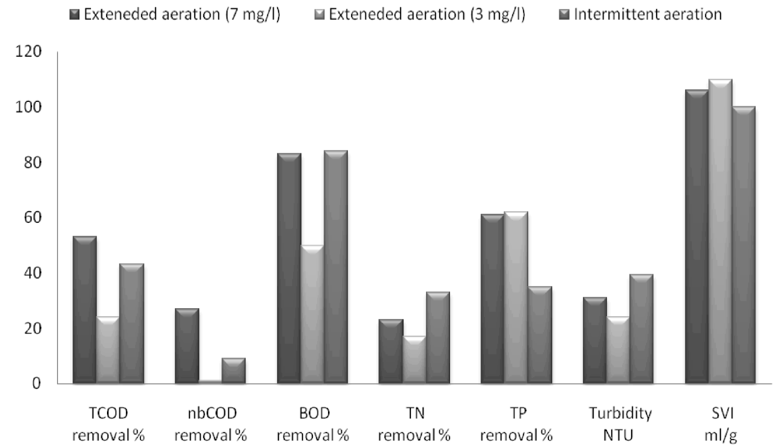

Fig. 10: The performance of the bioreactor at different aeration strategies

the rate of aeration and the other one; operating the system in intermittent aeration regime. Therefore, additional experiments were conducted.

In this section, treating the FIW was examined at MLVSS and aeration time of 4500 mg/l and 15 h with different aeration strategies (extended aeration with DO˜3 mg/l and intermittent aeration with 40 min/h). In order to analyze and compare the process performance of the system, seven process and quality parameters were measured or calculated, as shown in Fig.10. Reduction in the oxygen level from 7 to 3 mg/l with the extended aeration mode resulted in a decrease in TCOD, nbCOD and BOD removal efficiencies. It was because of the less oxidation potential compared to the condition with DO ˜7 mg/l. This condition decreased the TN removal. The oxygen concentration had diminutive effect on TP removal. The effluent turbidity improved in the low DO concentration, implying more favored condition relative to the high DO concentration [34].

In the second step, the intermittent aeration applied (40 min/h) led to a decrease in TCOD, nbCOD, TP removal and SVI and an increase in BOD, effluent turbidity and TN removal. In conclusion, by optimizing the operation conditions (cycle time, aeration time) under intermittent aeration, the process performance of the SBR removing CNP from the FIW can be improved.

CONCLUSIONS

This study investigated the performance of SBR in biological treatment of Faraman’s industrial estate wastewater (FIW) by varying two factors (MLVSS concentration and aeration time). The experimental work, along with the data analysis, led to the following conclusions. The results showed that the maximum COD removal of 73.89% was obtained at the highest value of the factors (24 h and 7000 mg/l). The maximum value of TN removal efficiency was found to be 36.39 %. The MLVSS concentration was found to be the most significant variable on effluent turbidity. DO reduction in the system improved TN removal.

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REFERENCE

1. Knepper, T.P., J. Muller, T. Wulff and A. Maes, 2000. Unknown bis-ethyl-iso-octanol isolation and occurrence in surface water. J. Chromatogr. A, 889: 245-252.
2. Yi, S.H., W.Q. Zhuang, B. Wu, S.T.L. Tay and J.H. Tay, 2006. Biodegradation of p-Nitro phenol by Aerobic Granules in a Sequencing batch reactor. Environ. Sci. Technol., 40(7): 2396-2401.

3. Agdag, O.N. and D.T. Sponza, 2005. Anaerobic/aerobic treatment of municipal landfill leachate in sequential two-stage up-flow anaerobic sludge blanket reactor (UASB)/completely stirred tank reactor (CSTR) systems. Process Biochem., 40(2): 895-902.
4. Kapdan, I.K. and S. Alparslan, 2005. Application *of* anaerobic-aerobic sequential system *to* real textile wastewater for color and COD removal. Enzyme Microb. Technol., 36(2-3): 273-279.
5. Najafpour, G.D., A.A.L. Zinatizadeh and L.K. Lee, 2006. Performance of a three-stage aerobic RBC reactor in food canning wastewater treatment. Biochem. Eng. J., 30(3): 297-302.
6. Gargouri, B., F. Karray. N. Mhiri. F. Aloui and S. Sayadi, 2011. Application of a continuously stirred tank bioreactor (CSTR) for bioremediation of hydrocarbon-rich industrial wastewater effluents. J. Hazard. Mater., 189(1-2): 427-434.
7. Isik, M. and D.T. Sponza, 2004. Anaerobic/aerobic sequential treatment of a cotton textile mill wastewater. Chem. Technol. Biotechnol., 79(11): 1268-1274.
8. Isik, M. and D.T. Sponza, 2006. Biological treatment of acid dyeing wastewater using a sequential anaerobic/aerobic reactor system. Enzyme Microb. Technol., 38(7): 887-892.
9. Tezel, U., E. Guven, T.H. Erguder and G.N. Demirer, 2001. Sequential (anaerobic/aerobic) biological treatment of dalaman SEKA Pulp and Paper Industry effluent. Waste Manage., 21(8): 717-724.
10. Bhang, S.H., E.T. Lim, G.T. Jeong, J.H. Park, S.H. Park, S.J. Kim and D.H. Park, 2008. Application of advanced treatment process for nitrogen compounds removal of industrial waste-water. J. Biosci.Bioeng., 23: 541-545.
11. Tchobanoglous, G., F. Burton and H.D. Stensel, 2003. Wastewater Engineering: Treatment and Reuse. McGraw-Hill, pp: 411-417.
12. Ecken felder, W.W., 2000. Industrial Water pollution control. McGraw-Hill, pp: 211-218.
13. Irvine, R.L. and P.A. Wilderer, 1997. Flemming, Controlled unsteady state processes and technologies-an overview. Water Sci. Technol., 35(1): 1-10.
14. Rahimia, Y., A. Torabiana. N. Mehrdadi and B. Shahmoradi, 2011. Simultaneous nitrification-denitrification and phosphorus removal in a fixed bed sequencing batch reactor (FBSBR). J. Hazard. Mater., 185(2-3): 852-857.
15. Box, G.E.P. and N.R. Draper, 1987. Empirical Model-Building and Response Surfaces. Wiley.
16. Bas, D. and I.H. Boyaci, 2007. Modeling and optimization ²: usability of response surface methodology. J. Food Eng., 78: 836-845.
17. Aghamohammadi, N., A.A. Hamidi Bin. I.M. Hasnain and A.A.L. Zinatizadeh, 2007. Powdered activated carbon augmented activated sludge process for treatment of semi-aerobic landfill leachate using response surface methodology. Biores. Technol., 98(18): 3570-3578.
18. Zinatizadeh, A.A.L., H. Younesi. H. Bonakdari, M. Pirsaheb, M. Pazouki, G.D. Najafpour and I.M Hasnain, 2009. Effects of process factors on biological activity of granular sludge grown in an UASFF bioreactor. Renewable Energy. 34(5): 1245-1251.
19. Hadavifar, M., A.A.L. Zinatizadeh. H. Younesi and M. Galehdar. Fenton and photo-Fenton treatment of distillery effluent and optimization of treatment conditions with response surface methodology. Asia-pacific J. Chemical Engineering. 5(3): 454-464.
20. Khuri, A.I. and J.A. Cornell,1996. Response surfaces: design and analyses. Marcel Dekker.
21. American Public Health Association (APHA), 1999. Standard methods for the examination of water and wastewater, 20th ed; Washington, DC: APHA.
22. Dincern, A.R., N. Karakaya. E. Gunes and Y, 2008. Gunes. Removal of COD from oil recovery industry wastewater by the advanced oxidation processes (AOP) based on H_2O_2. Global Nest. 10(1): 31-38.
23. Chan, Y.J., M.F. Chong. Ch.L. Law and D.G. Hassell. A review on anaerobic-aerobic treatment of industrial and municipal wastewater. Chem. Eng. J., 155(1-2): 1-18.
24. Droste, R.L., 1997. Theory and practice of water and wastewater treatment. John Wiley.
25. Najafpour, G.D., H.A. Yieng. H. Younesi and A.A.L Zinatizadeh. Effect of organic loading on performance of rotating biological contactors using Palm Oil Mill effluents. Process Biochem., 40(8): 2879-2884.
26. Abdelrasoul, F.M., 2001. A comparative syudy of the BOD rate constant of industrial wastewater and sewage. Sixth International Water Technology Conference, Alexandria, Egypt, IWTC.
27. Rittmann, B.E. and P.L. Mc Carty, 2003. Environmental Biotechnology: principle and applications. McGraw-Hill.

28. Lina, N., A. Ghunmia and A.I. Jamrah, 2006. Biological treatment of textile wastewater using sequencing batch technology Environ. Model. Assess. 11(4): 333-343.
29. Verenich, S. and J. Kallas, 2002. Wet Oxidation Lumped Kinetic Model for Wastewater Organic Burden Biodegradability Prediction. Environ. Sci. Technol., 36(15): 3335-3339.
30. Davies, P.S., 2005. The Biological Basis of Wastewater Treatment. Strathkelvin Instruments.
31. Chang, H.N., R.K. Moon, B.G. Park, S.J. Lim, D.W. Choi, W.G. Lee, S.L. Song and Y.H. Ahn, 2000. Simulation of sequential batch reactor (SBR) operation for simultaneous removal of nitrogen and phosphorus. Bioprocess. Eng., 23(5): 513-521.
32. Debik, E. and N. Manav, 2010. Sequence optimization in a sequencing batch reactor for biological nutrient removal from domestic wastewater. Bioprocess Biosyst. Eng., 33(5): 533-540.
33. Yilmaz, G., R. Lemaire. J. Keller and Z.H. Yuan, 2008. Simultaneous Nitrification, Denitrification and Phosphorus Removal From Nutrient-Rich Industrial Wastewater Using Granular Sludge. Biotechnol Bioeng. 100(30): 529-41
34. Wan, J., Y. Bessiere and M. Sperandio, 2009. Alternating anoxic feast/aerobic famine condition for improving granular sludge formation in sequencing batch airlift reactor at reduced aeration rate. Water Res., 43(20): 5097 - 5108.