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Colour removal of tannery wastewater using salt tolerant microorganisms in a sequential batch reactor

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ABSTRACT

The sequential batch reactor (SBR) technology is being applied in a large number of treatment processes owing to the operational flexibility it offers. SBR's capability to carry flow equalization, biological processes, and secondary clarification within a single reactor by differing the time period of different phases and duration of aeration proves it a flexible process for wastewater treatment. In this study SBR was employed to treat the tannery industry wastewater for removing colour. The phase of the SBR was observed over a period of 50 d. Statistical based experiments were performed for optimizing the parameters viz., pH, temperature, inoculum's concentrations, agitation speed and initial concentration of the substrates on the treatment of wastewater from tanneries by the mixed culture derived from the tannery common effluent treatment plant sludge, in a batch reactor under aerobic condition. At the optimized conditions, experiments were performed by salt tolerant microorganisms such as *Pseudomonas aeruginosa, Bacillus flexus, Exiguobacterium homiense* and *Staphylococcus aureus* at various organic loading rate (OLR) by varying tannery wastewater concentration and hydraulic retention time (HRT) for colour removal. A maximum decolourization 94% was obtained in SBR with the OLR 0.312 kg COD/m^3 d, HRT 5 d for the substrate's initial concentration of 1,560 mg COD/L.

Keywords: Common effluent treatment plant (CETP); Colour removal; Hydraulic retention time (HRT); Organic loading rate (OLR); Sequential batch reactor (SBR); Tannery wastewater

1. Introduction

Various industrial activities produce hyper saline effluents. Leather tanning is a wet process that produces a lot of extremely saline liquid waste. The effluent has complex characteristics as a result of the various chemicals used at various stages of the hide and skin production. Various studies [1–3] have already reported on the details of wastewater created by tanneries, as well as its properties. Sunlight's influence on colour removal, chemical oxygen demand (COD) and suspended solids of Vat dyeing effluents was studied by Ansari and Thakur [4]. Dye and its intermediates, which are generally harmful and carcinogenic to the flora and fauna of water bodies, disturb the endocrine systems, cause significant pollution and aesthetic harm, and reduce the penetration of light in water, which has a detrimental impact on photosynthesis [5]. Tannery wastewater is dark brown and foul-smelling, owing to the huge concentrations of organic and inorganic compounds present [6]. Leather is immersed in a dying liquid, also known as dye liquor or solution, during the dyeing process. The dye liquid usually consists of a dye, water, and other additives. The discharge of tannery effluent containing such harmful pollutants into the environment causes substantial soil and water pollution, which

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has an impact on human and other living species' health. The leather industry wastewater has a significant impact on humans, producing nose and skin irritation as well as lung cancer [7,8]. As a result, it is critical that tannery effluents be treated before being released into the environment.

The complex composition of organic and inorganic compounds in high-concentration pollutants creates a problem for treatment approaches [9,10]. Coagulation, ozonation, membrane process, filtration with coagulation, ozonation with coagulation, and adsorption under physical and chemical modes [11–15] are effective decolorization methods, but they require a lot of energy and chemicals, which necessitates additional treatments to remove pollutants in concentrated form. Biological treatment approaches can totally eliminate contaminants and are usually less expensive [16]. Different microorganisms, notably *Cellulosimicrobium* sp. [17], *Bacillus* sp. [18–20], *Thiobacillus* sp. [21], *Planococcus* sp. [22], *Stenotrophomonas* sp. [23], *Penicillium* sp. and *Fusarium* sp. [24] have been studied for the treatment of leather industry waste water. Microorganisms with a high salt tolerance can withstand high salt concentrations and extract organics from saline effluent like tannery wastewater. *Pseudomonas aeruginosa*, *Bacillus flexus*, *Exiguobacterium homiense*, and *Staphylococcus aureus*, which are separated from oceanic and leather industry saline wastewater samples, were tested with consortia in pure and mixed form of four salt tolerant bacterial strains [25]. The found salt-tolerant bacterial consortia is thought to be a good working culture for biodegrading tannery saline effluent efficiently. The goal of this study was to assess the sequential batch reactor (SBR's) ability to treat tannery effluent for colour removal.

The sequencing batch reactor (SBR) is a variation of the activated sludge method that has been used to treat municipal and industrial wastewater with great success [26]. In wastewater treatment plants, SBR technology is becoming increasingly important. It is well-known for being a tough system that can withstand hard circumstances, and it is frequently used to treat wastewater. The key advantages are ease of operation, relatively inexpensive, handling hydraulic fluctuation, no requirement for a settling tank, sludge recycling, and organic load removal efficiency without substantial change [27]. Some research has been done on the use of halophiles in SBR to degrade complicated wastewater [28]. The goal of this research is to treat tannery wastewater in an SBR by altering the hydraulic retention time, initial substrate concentration, and studying the kinetics of tannery wastewater degradation.

2. Materials and methods

2.1. Substrate

The leather industry wastewater and seed sludge were collected from the Ranipet Tannery Effluent Treatment Co. Ltd., V.C. Mottur, Walajah, South India, and used as an influent for the bioreactor.

2.2. Experimental setup: sequential batch reactor

A reactor was made up of two laboratory-scale plexiglass reactors (SBR-1 and SBR-2), each having a capacity of 10 L. Fig. 1 depicts a schematic diagram of the experimental setup. Using peristaltic pumps, tubes were placed into the reactors to assume the filling and removal of the effluent. The reactors were supplied with O_2 via a tiny bubble air diffuser. A mechanical stirrer spinning at 150 rpm was used to agitate the contents of the reactors. Every period takes 24 h: 1 h for filling, 20 h for reaction, 2 h for setting, 0.75 h for withdrawal, and 0.25 h for idle. The reactor (SBR-1) was inoculated with the sludge-derived mixed consortium. Fig. 2 shows a snapshot of the process.

2.3. Reactor inoculation and start-up

The tannery process effluent was pumped into the reactor (SBR-1). The inoculum was made from sludge from a wastewater treatment plant for the leather industry. It was added to the procedure to start microorganism growth. Air was delivered at an 8 cc/s rate, and the pH was kept between 6.9 and 7.1. The pH value of 7 was found to be optimal for the improved degradation of tannery effluent employing sludge [26]. The set-up was left for half a month

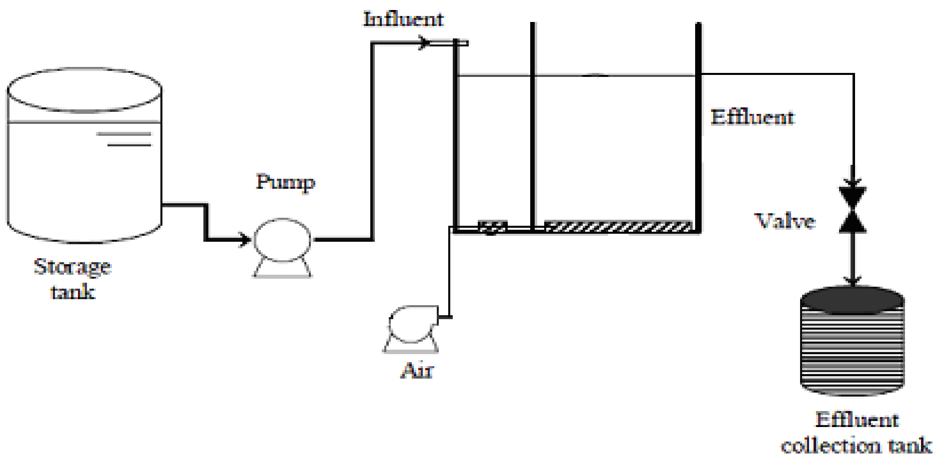

Fig. 1. Schematic of sequential batch reactor set up.

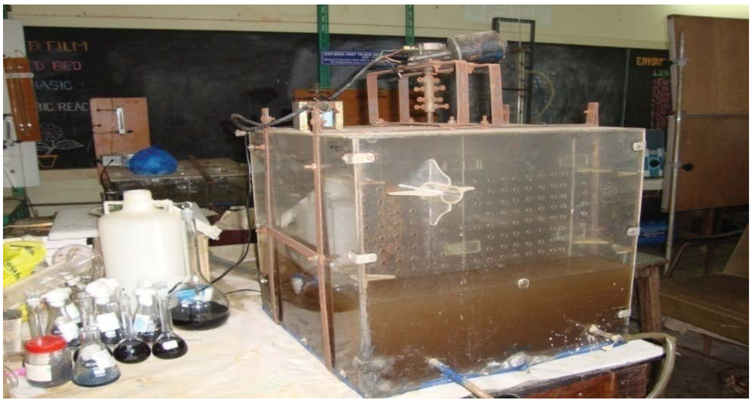

Fig. 2. Photograph of SBR.

with aeration to allow the microorganisms to acclimate. The influent was then fed into the process for treatment, and O_2 was passed at the same rate.

The same approach was used to inoculate SBR-2 with salt-tolerant bacteria such as *Pseudomonas aeruginosa*, *Bacillus flexus*, *Exiguobacterium homiense*, and *Staphylococcus aureus*. The temperature and pH were kept at 37°C and 7.5, respectively [29].

2.4. Experimental procedure

At different organic loading rate (OLRs), the reactor (SBR-1) was treated for initial concentrations of 1,560; 3220; 4,680; and 6,240 mg COD/L. For the first 15 d, an organic loading rate of 0.319 kg COD/m^{3}d was maintained. On the 16th day, the organic loading rate was increased to 0.39 kg COD/m^3. The organic loading rate was kept at 0.52 kg COD/m^3 from the 32nd to the 40th day. Continued to maintain an organic loading rate of 0.78 kg COD/m^3, the experiment was terminated. As a result, the hydraulic retention time (HRT) for the process was set to 5, 4, 3, and 2 d. The SBR process conditions are listed in Table 1.

The reactor must be fully aerated throughout the influent feeding (1 h). After then, the aeration was continued for another 20 h (react step: aeration). After then, aeration was turned off for 2 h (settle step: sedimentation). The supernatant was to be withdrawn within 0.75 h (draw phase: decant) after the bio-sludge had settled completely, and the system had to be kept idle for 0.25 h (idle step). The procedure was restarted with fresh influent and the above conditions were repeated. Excess bio-sludge was removed from the reactor during the idle stage to keep the bio-sludge concentration within the permitted range. The procedure was carried out for 50 d while adhering to the operating conditions outlined in Table 1. The method recommended by Bajpai et al. [30] was used to examine colour reduction. The pH was corrected to 7.6 after centrifuging the sample at 10,000 rpm for 0.5 h. At 465 nm, the absorbance was measured and converted to colour units. Experiments with different beginning substrate concentrations were also carried out.

In SBR-2, the same approach was used. After the trials were completed, a sorbent, wheat bran (10 g/L), was added to the reactors and the colour reduction procedure was repeated.

Table 1
Operating conditions of SBR

Substrate concentration, mg COD/L	Day	HRT, d	OLR, kg COD/m^3 d
1,560	1–15	5	0.312
	16–31	4	0.390
	32–40	3	0.520
	41–50	2	0.780
3,220	1–15	5	0.644
	16–31	4	0.805
	32–40	3	1.070
	41–50	2	1.610
4,680	1–15	5	0.936
	16–31	4	1.170
	32–40	3	1.560
	41–50	2	2.340
6,240	1–15	5	1.308
	16–31	4	1.635
	32–40	3	2.180
	41–50	2	3.270

3. Result and discussion

3.1. Screening of sorbent for the treatment of tannery wastewater

Table 2 shows the results of experiments done in a batch reactor to choose a sorbent for the removal of colour in tannery effluent using the Plackett–Burman design. According to the Pareto chart (Fig. 3), wheat bran was the most effective sorbent for reducing colour in leather manufacturing process waste water. As a result, it was used in the SBR.

3.2. Performance of SBR in colour removal from tannery wastewater

Color was one of the most critical parameters to eliminate from tannery wastewater. The wastewater from the tannery was mostly dark brown in colour. SBR was used to conduct colour reduction experiments using mixed culture (MC), salt tolerant microorganisms (STM), mixed

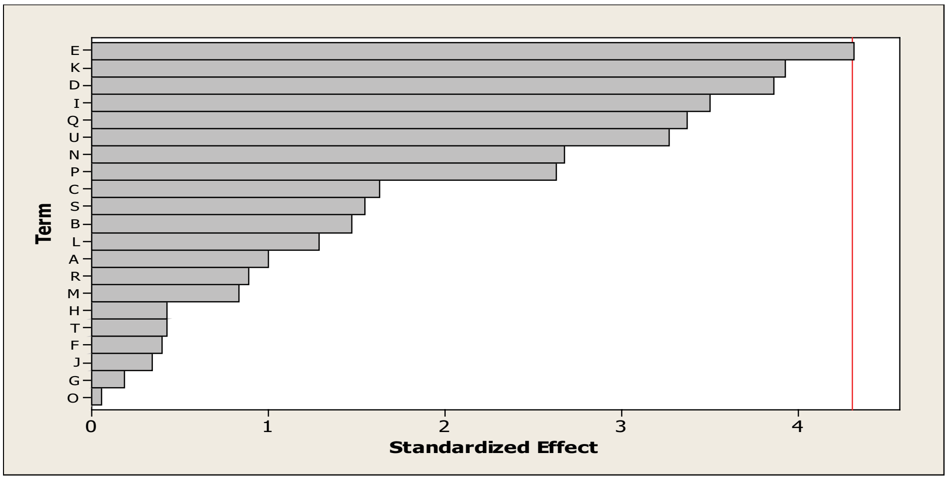

Fig. 3. Pareto chart for screening of sorbents.

Table 2
Selection of sorbent based on Plackett–Burman design

Run number	% Colour removal
1	61.0
2	46.3
3	40.1
4	51.2
5	46.5
6	50.8
7	52.1
8	48.7
9	61.2
10	49.6
11	47.5
12	38.2
13	44.3
14	43.5
15	55.2
16	56.9
17	41.2
18	44.3
19	52.3
20	57.8
21	44.6
22	55.6
23	48.3
24	51.2

culture with sorbent (MCS), and salt tolerant microorganisms with wheat bran sorbent (STMS). Figs. 4–7 depict the results achieved.

The colour reduction appears to be dependent on the microorganisms utilised, as shown in Figs. 4–7. The salt-tolerant microorganisms showed a greater ability to remove colour without the use of sorbent, as seen in Figs. 4–7. According to the results, adding wheat bran to SBR greatly increased the efficiency of removing colour. After adding wheat bran to SBR, the average efficiency of colour reduction utilising MCS and STMS was raised by 25%–30% and 6%–15%, respectively. The dye molecules sorption on the surface of the wheat bran sorbent resulted in an increase in colour decrease. The results show that both biodegradation and adsorption occurred in this SBR. Color removal was 54%, 84%, 78.6%, and 94% with MC, MCS, STM, and STMS, respectively. Wheat bran was also an effective technique to allow the biological process to continue operating in the presence of chromium, as seen by higher colour removal efficiency. Decolorization of textile dye wastewater showed a similar characteristic when the OLR was increased by adjusting the intake concentration. These data support Kapdan and Oztekin's [31] conclusions that SBR has a strong ability to withstand relatively substantial disturbances in input organic loading rate changes. They evaluated the impact of varying the starting dye concentration and HRT in an SBR with textile dye synthetic wastewater. They also discovered that lowering the HRT instantly reduces the decolorization and COD removal efficiency.

For various initial substrate concentrations and hydraulic retention times, Table 3 shows the highest percentage of colour removal. It also provided the OLR for different HRT. It was concluded from the table that as OLR increases, colour reduction decreases. Lower influent concentrations and shorter HRTs resulted in higher degrading efficiency [32].

3.3. Effect of organic loading rate and HRT on colour removal

Fig. 8 shows the relationship between the OLR and the colour removal efficiency for the reactor's overall efficiency. The removal efficiency was initially set at a relatively high level for low OLR (over 90%). The procedure yielded a different colour removal % for the same OLR because the reactor was operated at different initial substrate concentrations, as shown in the figure.

Fig. 9 shows the effect of HRT on colour removal. It was concluded from the figure that, regardless of microbes

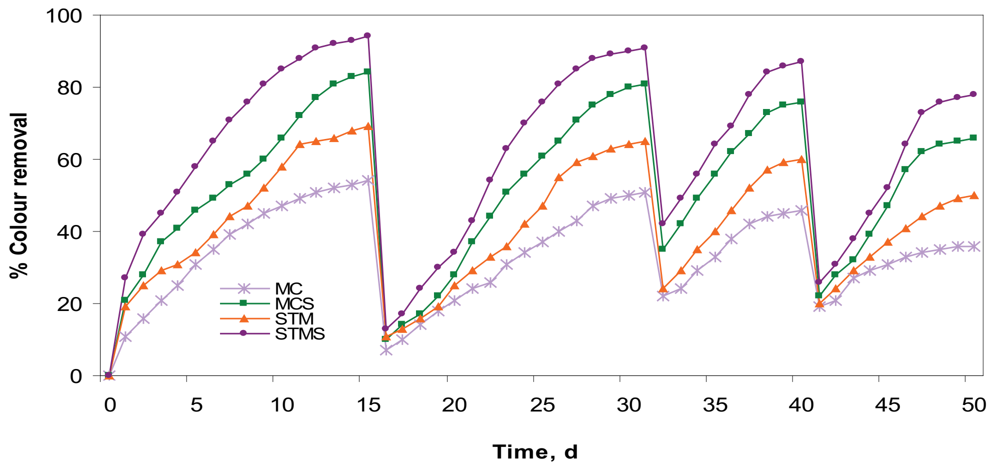

Fig. 4. Colour removal during tannery wastewater treatment in SBR – 1,560 mg COD/L.

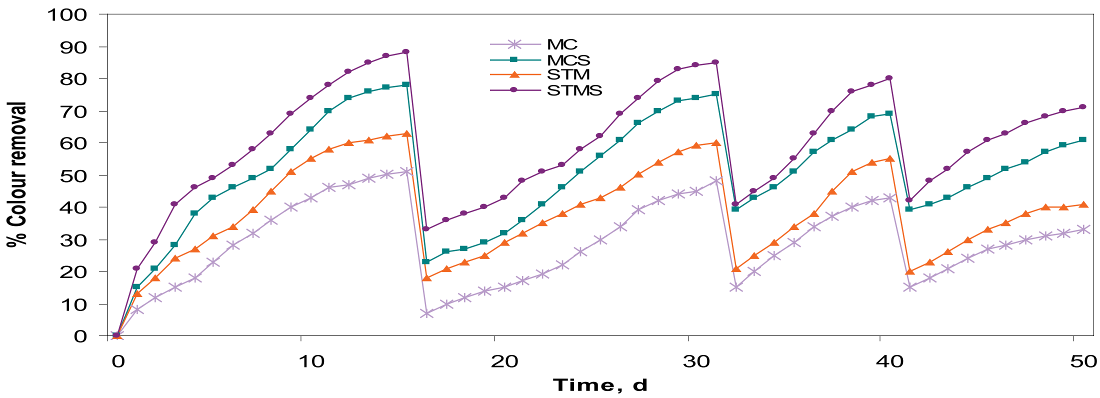

Fig. 5. Colour removal during tannery wastewater treatment in SBR – 3,220 mg COD/L.

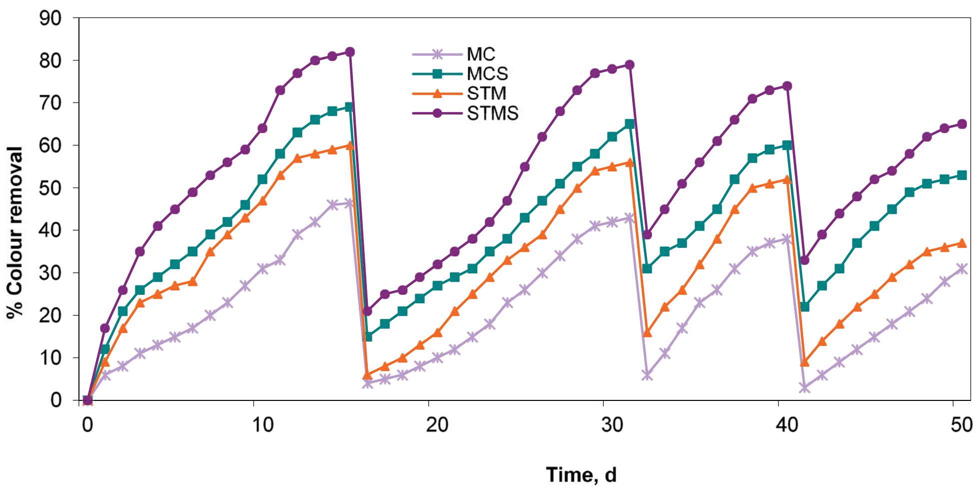

Fig. 6. Colour removal during tannery wastewater treatment in SBR – 4,680 mg COD/L.

or beginning substrate concentration, colour removal was observed to be greatest at high HRT. When HRT was reduced, the percentage colour removal also decreases, although the decline is most noticeable when HRT is dropped from three to 2 d. At the optimum hydraulic retention time, 3 d resulted in improved COD elimination for all concentrations [33].

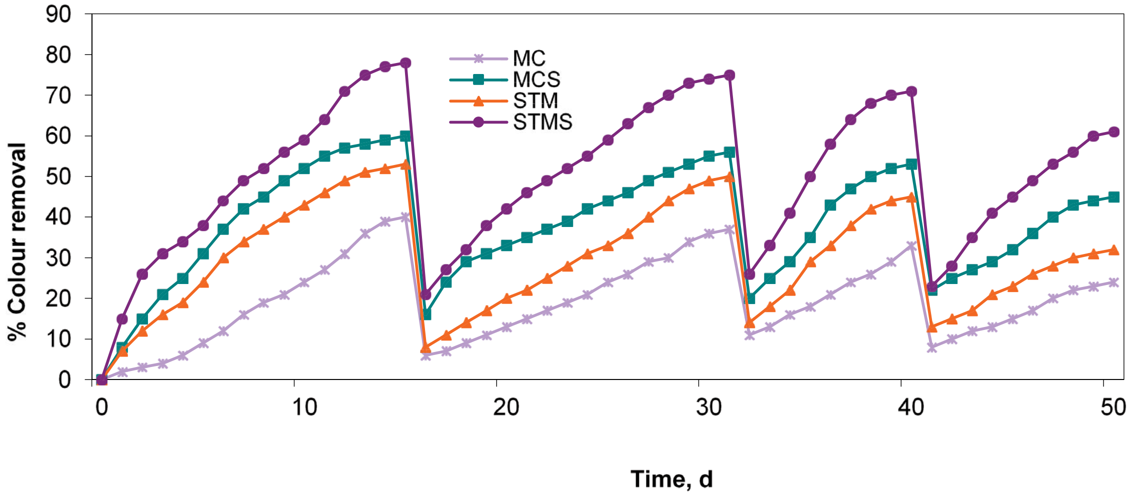

Fig. 7. Colour removal during tannery wastewater treatment in SBR – 6,240 mg COD/L.

Table 3
Performance of SBR at various substrate concentration, hydraulic retention time and organic loading rate for colour removal

Substrate concentration, mg COD/L	HRT, d	OLR, kg COD/m³ d	% Colour removal			
			MC	MCS	STM	STMS
1,560	5	0.312	54	84	78.6	94
	4	0.390	45	81	76	91
	3	0.520	39	76	74.6	87
	2	0.780	36	69	66	78
3,220	5	0.644	51	78	63	88
	4	0.805	48	75	60	85
	3	1.070	43	69	55	80
	2	1.610	33	61	41	71
4,680	5	0.936	46	69	60	82
	4	1.170	43	65	56	79
	3	1.560	38	60	52	74
	2	2.340	31	53	37	65
6,240	5	1.308	40	60	53	78
	4	1.635	37	56	50	75
	3	2.180	33	53	45	71
	2	3.270	24	45	32	61

4. Kinetics and modelling

4.1. Monod model

The Monod model was given by [34]:

$$\mu = \mu_{max}\left(\frac{S}{K_S + S}\right) \quad (1)$$

The experimental values were used to find out the parameters and to verify the applicability of the model. Biomass was plotted against time and dx/dt values were found. From this, μ values were calculated. Solving Monod model in MATLAB 7.0 the constants were found. The COD reduction profile was well explained by Monod model with high values of R^2 (0.9) at various initial substrate concentrations and it was given in Table 4. Form the table it was inferred that the rate constant decreases for the increase in the initial substrate concentration. The high R^2 values showed the applicability of this model in explaining the batch kinetics of the degradation of tannery wastewater.

4.2. Contois model

The Contois model [35] is:

$$\mu = \left(\frac{\mu_{max} S}{BX + T}\right) \quad (2)$$

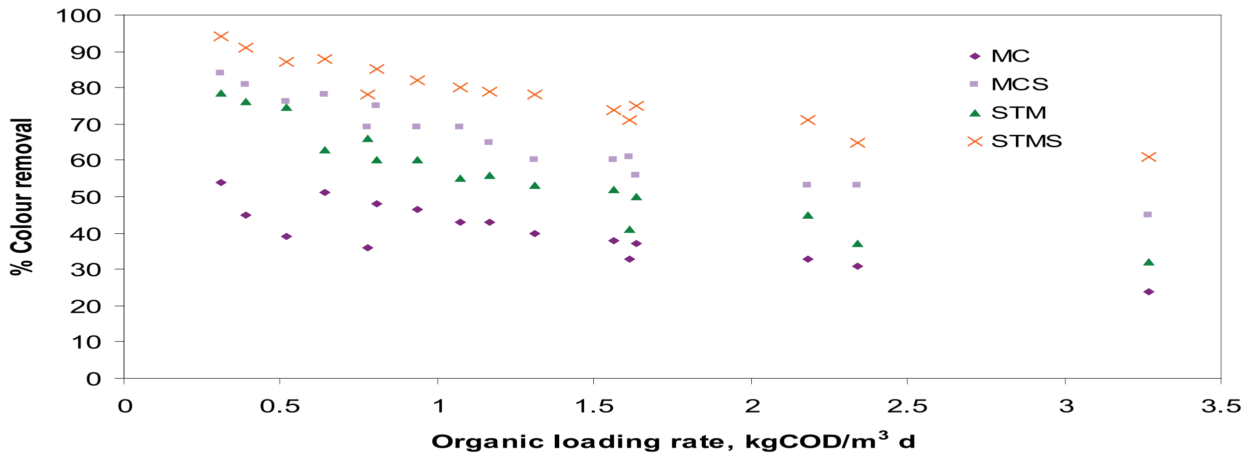

Fig. 8. Effect of organic loading rate on colour removal efficiency.

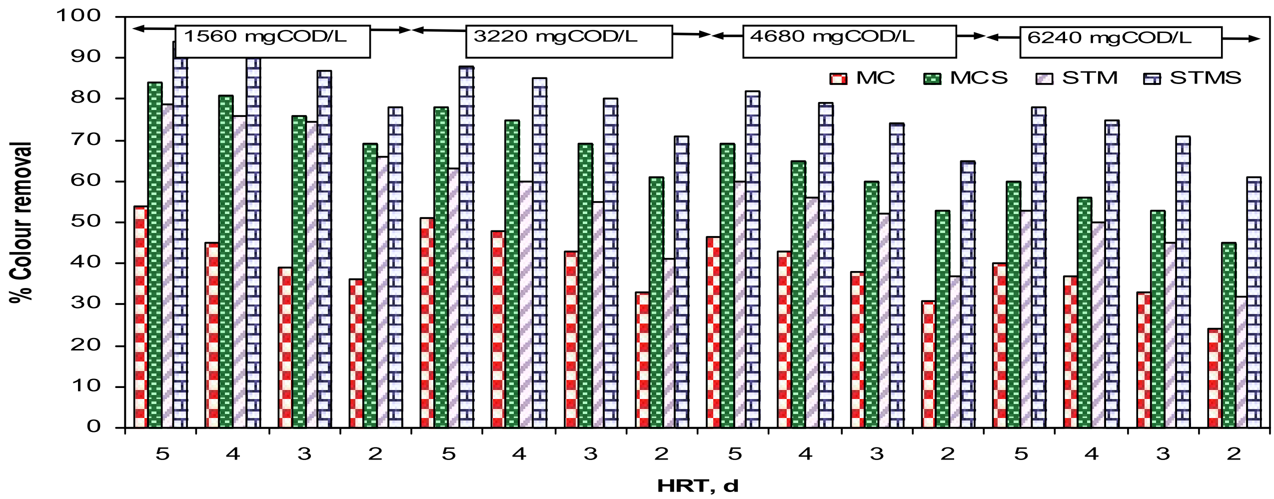

Fig. 9. Effect of HRT on colour removal efficiency.

Table 4
Performance of various kinetics models in batch degradation

Model	Initial substrate concentration, mg COD/L	K_s (mg/L)/B	μ_{max} (mg/mg/h)	RMSE	R^2
Monod model		998.5	0.8321	0.95	0.9012
Contois model	1,560	665	0.6354	9.21	0.8112
Moser model		1,685	0.7245	10.10	0.8002
Monod model		1,123	0.7235	1.06	0.9210
Contois model	3,220	836	0.6112	8.35	0.8035
Moser model		2,136	0.5523	9.12	0.7985
Monod model		1,325	0.5352	1.15	0.9123
Contois model	4,680	1,012	0.4237	10.21	0.7826
Moser model		3,023	0.5001	12.31	0.7223
Monod model		1,752	0.3225	1.37	0.9001
Contois model	6,240	2,114	0.3235	11.65	0.7336
Moser model		5,023	0.2685	13.24	0.7023

Table 5
Kinetic values obtained from various inhibition models in batch degradation

Model	μ_{max} (mg/mg/h)	K_s (mg/L)	K_i	K_1	RMSE	R^2
Tessier model	4.56	3.256	2.365	–	2.3520	0.6587
Haldane model	2.365	165.32	112.5	–	0.0245	0.9435
Webb model	10.352	–3.65	48.32	1.654	2.3640	0.7352

The experimental values were used to describing the parameters and to verify the applicability of the model. Biomass was plotted against time and *dx*/*dt* values were found and given in Table 4. From this, μ values were calculated. Solving Contois model in MATLAB 7.0, the constants were found. R^2 value indicated that the Contois model didn't fit the data well.

4.3. Moser model

The Moser model can be written as [36]:

$$\mu = \frac{\mu_{max} S^2}{K_S + S^2} \tag{3}$$

The experimental values were used to describe the parameters and to verify the applicability of the model. Solving Moser model in MATLAB 7.0, the constants were found. But the R^2 value, showed that the Moser model didn't fit the data well.

4.4. Tessier model

The Tessier model can be written as [37]:

$$\mu = \mu_{max}\left[\exp\left(\frac{-S}{K_i}\right) - \exp\left(\frac{-S}{K_s}\right)\right] \tag{4}$$

The constants in the model were evaluated using MATLAB 7.0 and they are given in Table 5. This model was also unable to describe the kinetics of tannery waste water, which was indicate by low R^2 value.

4.5. Haldane model

The Haldane model [38] is given by:

$$\mu = \frac{\mu_{max} S}{K_s + S + \dfrac{S^2}{K_i}} \tag{5}$$

The experimental values were used to describe the parameters and to verify the suitability of the model. The constants in the model were evaluated using MATLAB 7.0. It was found that Haldane model showed the ability for describing the kinetics of tannery wastewater degradation, which was indicated by high R^2 value. This described that the substrate inhibition occurs during tannery wastewater treatment. The constants and R^2 values are given in Table 5.

4.6. Webb model

Webb model [36] can be written as:

$$\mu = \mu_{max} \frac{S\left(1 + \dfrac{S}{K_i}\right)}{K_s + S + \dfrac{S^2}{K_1}} \tag{6}$$

The constants in the model were evaluated using MATLAB 7.0. But this model was found unable in describing the degradation kinetics of tannery waste water, which is indicated by the lower R^2 value. The constants and R^2 values are given in Table 5.

5. Conclusions

By adjusting parameters such as initial substrate concentration, HRT, and OLR, a sequential batch reactor was employed to continually degrade tannery waste water by a mixed culture produced from tannery sludge. The reactor's efficiency demonstrated that SBR had a high level of colour removal (94%). A drop in HRT results in a decrease in colour reduction. When HRT is reduced, the percentage colour removal also decreases, although the decline is most noticeable when HRT is dropped from three to 2 d. At the optimum hydraulic retention time, 3 d was shown to be the best time for COD elimination for all concentrations. The degradation of tannery wastewater in SBR follows the Monod and Haldane model, according to the kinetic and inhibition investigations. The Moser, Contois, Tessier, and Webb models, on the other hand, failed to describe the degradation process. This study indicates that utilising salt-tolerant microorganisms, SBR can be used to remove the colour from tannery waste water.

References

[1] S. Saja, A. Bouaziz, B. Achiou, M. Ouammou, A. Albizane, J. Bennazha, S. Alami Younssi, Elaboration and characterization of low-cost ceramic membrane made from natural Moroccan perlite for treatment of industrial wastewater, J. Environ. Chem. Eng., 6 (2018) 451–458.

[2] S. Elabbas, N. Ouazzani, L. Mandi, F. Berrekhis, M. Perdicakis,S. Pontvianne, M.-N. Pons, F. Lapicque, J.-P. Leclerc, Treatment of highly concentrated tannery wastewater using electrocoagulation: influence of the quality of aluminium used for the electrode, J. Hazard. Mater., 319 (2016) 69–77.

[3] K. Elkarrach, M. Merzouki, O. Laidi, A. Omor, M. Benlemlih, Treatment of tannery effluents of Fez city by the sequential batch reactor, Eur. J. Sci. Res., 150 (2018) 334–348.

[4] A.A. Ansari, B.D. Thakur, Biochemical reactor for treatment of concentrated textile effluent, Colourage, 2 (2006) 27–31.

[5] O. Adeyi, O.S. Ayanda, G.O. Olutona, O. Ganiyu, Adsorption kinetics and intra-particulate diffusivity of aniline blue dye onto activated plantain peels carbon, Chem. Sci. Trans., 2 (2013) 294–300.

[6] R. Bharose, S. Parveen, D. Singh, Assessment of physico-chemical properties of tannery waste water and its impact on fresh water quality, Int. J. Curr. Microbiol. Appl. Sci., 6 (2017) 1879–1887.

[7] A.R. Khan, I. Ullah, A.L. Khan, G.-S. Park, M. Waqas, S.-J. Hong, B.K. Jung, Y. Kwak, I.-J. Lee, J.-H. Shin, Improvement in phytoremediation potential of *Solanum nigrum* under cadmium contamination through endophytic-assisted *Serratia* sp. RSC-14 inoculation, Environ. Sci. Pollut. Res., 22 (2015) 14032–14042.

[8] S. Dhanarani, E. Viswanathan, P. Piruthiviraj, P. Arivalagan, T. Kaliannan, Comparative study on the biosorption of aluminum by free and immobilized cells of *Bacillus safensis* KTSMBNL 26 isolated from explosive contaminated soil, J. Taiwan Inst. Chem. Eng., 69 (2016) 61–67.

[9] S.G. Schrank, U. Bieling, H.J. Jose, R.F.P.M. Moreira, H.F. Schroder, Generation of endocrine disruptor compounds during ozone treatment of tannery wastewater confirmed by biological effect analysis and substance specific analysis, Water Sci. Technol., 59 (2009) 31–38.

[10] A.N. Modenes, F.R. Espinoza-Quiñones, F.H. Borba, D.R. Manenti, Performance evaluation of an integrated photo-fenton–electrocoagulation process applied to pollutant removal from tannery effluent in batch system, Chem. Eng. J., 197 (2012) 1–9.

[11] Sheng H. Lin, Chi M. Lin. Treatment of textile waste effluents by ozonation and chemical coagulation, Water Res., 27 (1993) 1743–48.

[12] M. Fadhil Abid, M. Abdulahad Zablouk, A. Muhssen Abid-Alameer, Experimental study of dye removal from industrial wastewater by membrane technologies of reverse osmosis and nanofiltration, Iran. J. Environ. Health Sci. Eng., 9 (2012) 17, doi: 10.1186/1735-2746-9-17.

[13] A.Y. Zahrim, N. Hilal, Treatment of highly concentrated dye solution by coagulation/flocculation–sand filtration and nanofiltration, Water Resour. Ind., 3 (2013) 23–34.

[14] M.A. García-Morales, G. Roa-Morales, C. Barrera-Díaz, V. Martínez Miranda, P. Balderas Hernández, T.B. Pavón Silva, Integrated advanced oxidation process (Ozonation) and electrocoagulation treatments for dye removal in denim effluents, Int. J. Electrochem. Sci., 8 (2013) 8752–8763.

[15] E. Meabe, S. Déléris, S. Soroa, L. Sancho, Performance of anaerobic membrane bioreactor for sewage sludge treatment: mesophilic and thermophilic processes, J. Membr. Sci., 446 (2013) 26–33.

[16] E. Messay, D. Mekibib, Two-stage anaerobic sequence batch digestion of composite tannery wastewater, Afr. J. Environ. Sci. Technol., 11 (2017) 578–586.

[17] R.N. Bharagava, S. Mishra, Hexavalent chromium reduction potential of *Cellulosimicrobium* sp. isolated from common effluent treatment plant of tannery industries, Ecotoxicol. Environ. Saf., 147 (2018) 102–109.

[18] S.P. Bachate, V.S. Nandre, N.S. Ghatpande, K.M. Kodam, Simultaneous reduction of Cr(VI) and oxidation of As(III) by *Bacillus firmus* TE7 isolated from tannery effluent, Chemosphere, 90 (2013) 2273–2278.

[19] R.O. Yusuf, Z.Z. Noor, M.A.A. Hassan, S.E. Agarry, B.O. Solomon, A comparison of the efficacy of two strains of *Bacillus subtilis* and *Pseudomonas fragii* in the treatment of tannery wastewater, Desal. Water Treat., 51 (2013) 3189–3195.

[20] V. Kumari, A. Yadav, I. Haq, S. Kumar, R.N. Bharagava, S.K. Singh, A. Raj, Genotoxicity evaluation of tannery effluent treated with newly isolated hexavalent chromium reducing *Bacillus cereus*, J. Environ. Manage., 183 (2016) 204–211.

[21] T. Mandal, D. Dasgupta, S. Mandal, S. Datta, Treatment of leather industry wastewater by aerobic biological and Fenton oxidation process, J. Hazard. Mater., 180 (2010) 204–211.

[22] M. Behera, D. Dhali, S. Chityala, T. Mandal, P. Bhattacharya, D.D. Mandal, Evaluation of performance of *Planococcus* sp. TRC1 an indigenous bacterial isolate monoculture as bioremediator for tannery effluent, Desal. Water Treat., 57 (2016) 13213–13224.

[23] N.M. Raman, S. Asokan, N.S. Sundari, S. Ramasamy, Bio-remediation of chromium(VI) by *Stenotrophomonas maltophilia* isolated from tannery effluent, Int. J. Environ. Sci. Technol., 15 (2018) 207–216.

[24] S. Sharma, M.G. Dastidar, T.R. Sreekrishnan, Zinc uptake by fungal biomass isolated from industrial wastewater, Pract. Period. Hazard. Toxic Radioact. Waste Manage., 6 (2002) 256–261.

[25] S. Sivaprakasam, S. Mahadevan, S. Sekar, S. Rajakumar, Biological treatment of tannery wastewater by using salt-tolerant bacterial strains, Microb. Cell Fact., 7 (2008) 105–112.

[26] P.A. Herzbrun, R.L. Irvine, K.C. Malinowski, Biological treatment of hazardous waste in sequencing batch reactors, J. Water Pollut. Control Fed., 57 (1985) 1163–1167.

[27] L.O. Keudel, N.J. Dichtl, Settling Characteristics of Activated Sludge in Sequencing Batch Reactors Obtained from Full-Scale Experiments, 2nd International Symposium on Sequencing Batch Reactor Technology, Narbone, 10–12 July 2000, pp. 75–83.

[28] O. Lefebvre, F. Habouzit, V. Bru, J.P. Delgenes, J.J. Godon, R. Moletta Treatment of hypersaline industrial wastewater by a microbial consortium in a sequencing batch reactor, Environ. Technol., 25 (2004) 543–553.

[29] K. Yamamoto, K.M. Win, Tannery wastewater treatment using a sequencing batch membrane reactor, Water Sci. Technol., 23 (1991) 1639–1648.

[30] P. Bajpai, A. Mehna, P.K. Bajpai, Decolorization of Kraft bleach plant effluent with the white rot fungus *Trametes versicolor*, Process Biochem., 28 (1993) 377–384.

[31] I. Karapinar Kapdan, R. Oztekin, The effect of hydraulic residence time and initial COD concentration on color and COD removal performance of the anaerobic–aerobic SBR system, J. Hazard. Mater., 136 (2006) 896–901.

[32] K.L. Sublette, E.H. Sinder, N.D. Sylvester, A review of the mechanism of powdered activated carbon enhancement of activated sludge treatment, Water Res., 16 (1982) 1075–1082.

[33] N. Iwami, A. Imai, Y. Inamori, R. Sudo, Treatment of a landfill leachate containing refractory organics and ammonium nitrogen by the microorganism-attached activated carbon fluidized bed process, Water Sci. Technol., 26 (1992) 1999–2002.

[34] C. Di Iaconi, A. Lopez, R. Ramadori, R. Passino, Tannery wastewater treatment by sequencing batch biofilm reactor, Environ. Sci. Technol., 37 (2003) 3199–3205.

[35] D.E. Contois, Kinetics of bacterial growth: relationship between population density and specific growth rate of continuous culture, J. Gen. Microbiol., 21 (1959) 40–50.

[36] S.K. Layokun, E.F. Umoh, B.O. Solomon, A kinetic model for the degradation of dodecane by *P. fluorescens* isolated from the oil polluted area, Warri in Nigeria, J. NSCHE, 16 (1987) 48–52.

[37] V.H. Edwards, The influence of high substrate concentrations on microbial kinetics, Biotechnol. Bioeng., 12 (1970) 679–712.

[38] J.F. Andrews, Dynamic model of the anaerobic digestion process, Am. Soc. Civ. Eng., 95 (1969) 95–116.