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Original

Treatment of high saline textile wastewater by activated sludge microorganisms

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Abstract

Textile wastewater is a combination of various chemicals and different types of dyes and has a salty nature. In this study, an SBR (sequencing batch reactor) was used to treat synthetic and real textile wastewaters in a 24 h cycle time. Remazol Brilliant Blue R, a reactive dye, was used as the model dye. Dye concentrations ranged from 125 mg/L to 500 mg/L, and TDS (total dissolved solids) concentrations ranged from 1000 mg/L to 10,000 mg/L in synthetic wastewaters. For the highest dye concentration (500 mg/L) with low TDS, an 80.71% COD removal efficiency was obtained; at a TDS concentration of 5000 mg/L, a 59.44% COD removal efficiency was obtained. When the TDS concentration of wastewater was raised to 10,000 mg/L, COD removal decreased to 14.92% and reductions in MLSS (mixed liquor suspended solids) and MLVSS (mixed liquor volatile suspended solids) concentrations were observed. According to the results, increasing the TDS concentration of wastewater up to 5000 mg/L did not affect COD removal efficiency of the activated sludge microorganisms in the treatment system.

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Keywords: Saline wastewater treatment; Sequencing batch reactor; Activated sludge microorganisms

1. Introduction

The textile industry is one of the largest sources of contaminant wastewater, because it uses high volumes of water in dyeing, printing, and finishing processes (Nigam, Banat, Singh, & Marchant, 1996). The most important material consumed by these industries, and thus the most important resulting contaminant, is dye, which is used in large amounts (Nigam et al., 1996). The wastewater from textile and printing industries contain high amount of color and carcinogenic compounds (Quan, Zhang, & Xu, 2015); synthetic dyes are resistant to removal because of their aromatic compounds, Remazol Brilliant Blue R (RBBR) – the model dye – is a synthetic textile dye which is frequently used in producing polymeric dyes. It is toxic and organo-pollutant dye

and has an anthraquinone structure (Javaid, Qazi, & Kawasaki, 2016).

Various chemicals like scattering materials, acids, alkalis, salts, detergents, and oxidations are added during dyeing to improve the dye adsorption and stability of fibers; the most important characteristic of textile wastewater is its salty nature. Cellulosic fibers are the most prevalent textile fibers. When these fibers are placed in water, they are negatively charged because of the ionization of the hydroxyl groups. The most appropriate dyes for these fibers are anionic dyes, such as reactive dyes. An electrical repulsive force between the anionic dye and the fiber causes a reduction in fiber staining (Dodangeh & Gharanjig, 2012). To solve this problem, NaCl is used in the dyeing bath. Salt neutralizes the fiber surface charge and causes increased dye adsorption. The additional amount of dye with high concentrations of salt in wastewater increases environmental contamination (Dodangeh & Gharanjig, 2012). According to different resources, salt range of textile wastewater is varied between 1000 and 10,000 mg/L (Salvadó, Mas, Menéndez, & Gracia, 2001; Yurtsever, Calimlioglu, Görür,

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Çınar, & Sahinkaya, 2016) and the textile industry interns almost 0.2 million tons of salts in the environment per year (Soares et al., 2017).

Wastewater resulting from the dying process is considered the most important contaminant of textile industry wastewater which causes the destruction of organisms, increases BOD concentrations, and decreases the supply of dissolved oxygen in the acceptor water environment (Chaeibakhsh Langroodi & Abedinzadeh, 2004).

Selecting the appropriate treatment method for wastewater with various chemicals and dyes is very important (Nigam et al., 1996). Different methods, including various chemical, physical, and biological treatments, have been applied for treating textile wastewater. Low dye removal efficiency restricts the application of physical methods such as adsorption and filtration methods (Vandevivere, Bianchi, & Verstraete, 1998). Chemical oxidation methods make the destruction and degradation of dyestuff molecules possible, but with these methods, various oxidizing agents such as O_3 , H_2O_2 , and MnO_4 are used. In addition to being unable to completely remove azo dyes from wastewater (because azo dyes are stable and resistant to degradation), these methods are not economical and even produce large quantities of sometimes toxic sludge (Anjaneyulu, Chary, & Raj, 2005).

Biological treatment methods have been selected to remove contamination from textile wastewater that contains salt, because they are cost-effective, non-toxic, sustainable, and environmentally friendly (Banat, Nigam, Singh, & Marchant, 1996; Xiao & Roberts, 2010).

The sequencing batch reactor is an effective activated sludge process used for treating saline wastewater (Mesquita, Amaral, Ferreira, & Coelho, 2009). This biological treatment method involves a strong system, simple function, and high flexibility in procedures (Mohan, Rao, Prasad, Madhavi, & Sharma, 2005).

Equalization, aeration, and clarification can all be achieved using a single batch reactor (SBR). The SBR is appropriate for wastewater treatment applications characterized by low or intermittent flow conditions. Different effluents such as municipal, domestic, hypersaline, tannery, brewery, dairy wastewaters, and landfill leachates can be treated using this biological system (Mace & Mata-Alvarez, 2002).

SBR is considered a biological system for decolorizing the textile dye including Blue Bezactive 150, a reactive dye; according to the results, decolourisation rates were obtained in the range of 88–97% for different volumetric dye loading rates (3–15 g dye/m³ d) (Khouni, Marrot, & Amar, 2012).

The color removal efficiency of the SBR system increased when mixed liquor suspended solids (MLSS) were increased. The color removal efficiency of disperse dye treatments (Disperse Blue 60 and Disperse Red 60) was over 98% at an MLSS of 4000 mg/L; COD and BOD₅ removal efficiencies were also quite high (Sirianuntapiboon & Maneewon, 2012).

According to different studies, high loads of salt (0.5–5%) decreases the efficiency of biological treatment in wastewater treatment plant (Salvadó et al., 2001); because saline loads reduce the metabolic functions of activated sludge microorganisms (Mahmoud & Davis, 1979; Woolard & Irvine, 1995) but, gradually adapting the microorganisms to high saline conditions

can help minimizing the effect caused by salt (Bassin, Dezotti, & Sant'Anna, 2011). A gradual increase in the salt concentration (from 0 to 30 g NaCl/L) has less impact on the COD removal in the aerobic system with salt-adapted microorganisms rather than the one with non-adapted biomass (Bassin et al., 2012).

With regard to the salty nature of textile wastewater, SBR was selected as the treatment system in the present study, the main purpose of which was to investigate the ability of the aerobic microorganisms of the activated sludge to remove dye from textile wastewater containing a high concentration of salts. So far, few studies have been done on treating wastewater containing dye under high saline conditions using the same treatment system.

2. Materials and methods

2.1. Dye, sludge, and synthetic textile wastewater

Remazol Brilliant Blue R ($C_{22}H_{16}N_2Na_2O_{11}S_3$) obtained from Iran Poplin textile factory was used as the model dye for all experiments. This is a reactive dye frequently used in the textile industry.

Activated sludge was obtained from the treatment plant of the pharmaceutical company Sobhan Darou Co. in Rasht, Iran because activated sludge microorganisms from the pharmaceutical factory were adapted with dyes and organic compounds.

At first, the synthetic wastewaters were made without adding salt to achieve basic adaptations with different concentrations of dye in microorganisms; synthetic wastewaters were made with dye concentrations of 125, 250, and 500 mg/L. Then, after evaluating the COD removal efficiency of the first three synthetic wastewater treatments, synthetic wastewater samples with TDS concentrations of 1000, 5000, and 10,000 mg/L were made with a dye concentration of 125 mg/L. NH_4Cl and KH_2PO_4 were added as supplementary nutrients based on a COD/N/P ratio of approximately 100/5/1 for all samples.

2.2. Equipment

A magnetic stirrer set (Taksan Co., Iran), a 2000-mL beaker, and an air pump were used for the SBR treatment system. Other equipment used in this study included a BOD measuring device (Aqualytic Co., Germany), a digital scale with the precision of 0/0001 g (Sartorius Co., Germany) for measuring the dye and salt, an oven (DENA Co., Iran), an electrical furnace (Iran Khodasaz Co.) for MLSS and MLVSS tests, a spectrophotometer (WPA, S2100 Diode Array model, USA) for measuring absorption at a maximum visible wavelength of 570 nm, and a portable device for measuring pH and TDS (ESICO Co., model 7200, USA).

All experiments were performed based on the standard methods for examining water and wastewater (APHA, 2005).

2.3. SBR treatment process

Based on the Sequencing Batch Reactor system, the treatment process was as follows:

Table 1
Characteristics of real textile wastewater sample.

Concentration	Absorption (570 nm)	COD (mg/L)	pH (mg/L)	TDS ^a (mg/L)	TSS ^b (mg/L)	Phosphorus (mg/L)	Nitrogen (mg/L)
Textile wastewater	1.387	140.80	7.50	1470	110	2.65	0

^a Total dissolved solids.

^b Total Suspended Solids.

The reactor was filled with 1500 mL synthetic wastewater and 500 mL activated sludge (*filling stage*). The magnetic stirrer and aeration pump were turned on to completely mix the synthetic wastewater and the aerobic microorganisms of the activated sludge for 22 h (*reaction stage*). Then, the magnetic stirrer and aeration pump were turned off to allow the suspended activated sludge to settle in the reactor (*settling stage*). Lastly, 1500 mL of treated wastewater was withdrawn from the reactor (*withdrawal stage*).

The treatment cycle was 24 h for each concentration, and the biological treatment process was repeated continuously for 7 days for all concentrations.

The temperature of the SBR system was 27 ± 2 °C.

2.4. Effect of pH on dye removal

Studying dye removal efficiency in various pH values was another objective of the present research. The pH values of the samples used in this study were adjusted using NaOH.

2.5. Real textile wastewater

Finally, real wastewater was collected from Iran Poplin textile factory for use in the study of dye and COD removal efficiency.

Real wastewater samples were transported to the laboratory and stored at 4 °C until their utilization.

As in the previously discussed process, 1500 mL of wastewater was mixed with 500 mL of activated sludge in the treatment reactor.

At first, the treatment process was performed on real textile wastewater which had a TDS concentration of 1470 mg/L for 7 days; then the TDS concentration of the wastewater was increased to 10,000 mg/L and the treatment process was repeated.

The analysis results of the real textile wastewater are displayed in Table 1.

3. Results and discussion

3.1. Absorption, COD, and TDS parameters

The test results of the studied parameters on raw and treated wastewaters are given in Tables 1 and 2 and Figures 1 and 2.

As seen in Figure 2, the absorption amounts are in the same range with small changes during the 7 days of treatment. The range of the changes is very low at 0.002–0.004 in all concentrations on some days of treatment.

Also the procedure changes of absorption amounts and COD concentrations are obvious with regard to various dye and TDS

Table 2
pH changes in raw and treated wastewater samples (during 7 days of treatment).

Concentration (mg/L)	pH
Raw (125 mg/L) ^a	7.20
Treated (125 mg/L)	7.0 ± 0.1
Raw (250 mg/L) ^b	7.20
Treated (250 mg/L)	7.0 ± 0.2
Raw (500 mg/L) ^c	7
Treated (500 mg/L)	7.0 ± 0.2
Raw (125-TDS = 1000 mg/L) ^d	7
Treated (125-TDS = 1000 mg/L)	7.0 ± 0.1
Raw (125-TDS = 5000 mg/L) ^e	7
Treated (125-TDS = 5000 mg/L)	8.0 ± 0.5
Raw (125-TDS = 10,000 mg/L) ^f	7
Treated (125-TDS = 10,000 mg/L)	7.60
Raw textile wastewater ^g	7.50
Treated textile wastewater	7.0 ± 0.5
Raw (Textile W.-TDS = 10,000 mg/L) ^h	7.50
Treated (Textile W.-TDS = 10,000 mg/L)	7.50

^a Synthetic wastewater with dye concentration of 125 mg/L.

^b Synthetic wastewater with dye concentration of 250 mg/L.

^c Synthetic wastewater with dye concentration of 500 mg/L.

^d Synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 1000 mg/L.

^e Synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 5000 mg/L.

^f Synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 10,000 mg/L.

^g Real wastewater from textile factory.

^h Real wastewater from textile factory with TDS concentration of 10,000 mg/L.

concentrations in raw and treated wastewater (Figs. 1 and 2); there is a logical connection between increasing the absorption amounts and increasing the COD concentrations in all samples.

The activated sludge microorganisms used in the SBR treatment reactor were treatment plant microorganisms from a pharmacy factory. Their adaptation with wastewater containing dye was predictable, and COD removal efficiency and the range of resultant absorption amounts confirmed this adaptation in all treated concentrations during the 7 days of treatment. The microorganisms' adaptation process was tested in each concentration for one week.

A study on removing RB-5 textile dye using activated sludge bacteria reported 100% dye removal after 48 h of starting treatment for synthetic wastewater with dye concentrations of 10 and 20 mg/L. This result indicates that there was an adaptation background in microorganisms with similar conditions in synthetic wastewaters (Bahmani, Rezaei Kalantari, Joneidi Jafari, & Javadi, 2009).

As seen in Figures 1 and 2, the absorption amounts and COD concentrations in raw and treated wastewater with a dye concentration of 125 mg/L and a TDS concentration of

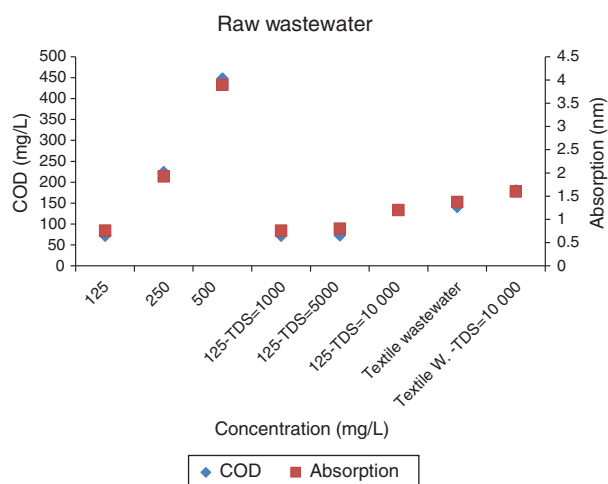


Fig. 1. Changes in COD concentrations and absorption amounts in 8 samples of raw wastewater. 125 mg/L: synthetic wastewater with dye concentration of 125 mg/L; 250 mg/L: synthetic wastewater with dye concentration of 250 mg/L; 500 mg/L: synthetic wastewater with dye concentration of 500 mg/L; 125-TDS = 1000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 1000 mg/L; 125-TDS = 5000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 5000 mg/L; 125-TDS = 10,000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 10,000 mg/L; Textile Wastewater: real wastewater from textile factory; Textile W.-TDS = 10,000 mg/L: real wastewater from textile factory with TDS concentration of 10,000 mg/L.

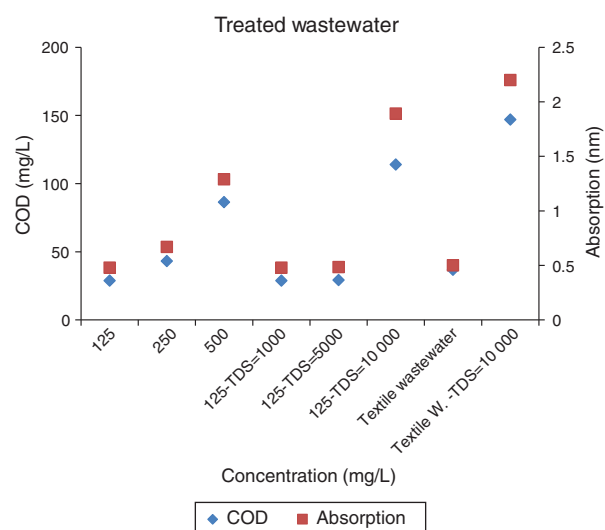


Fig. 2. Changes in COD concentrations and absorption amounts in 8 samples of treated wastewater. 125 mg/L: synthetic wastewater with dye concentration of 125 mg/L; 250 mg/L: synthetic wastewater with dye concentration of 250 mg/L; 500 mg/L: synthetic wastewater with dye concentration of 500 mg/L; 125-TDS = 1000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 1000 mg/L; 125-TDS = 5000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 5000 mg/L; 125-TDS = 10,000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 10,000 mg/L; Textile Wastewater: real wastewater from textile factory; Textile W.-TDS = 10,000 mg/L: real wastewater from textile factory with TDS concentration of 10,000 mg/L.

1000 mg/L are the same as those in the wastewater with a dye concentration of 125 mg/L and low salt. This result indicated that a TDS concentration of 1000 mg/L did not affect the treatment efficiency of microorganisms.

In the wastewater with a dye concentration of 125 mg/L and a salt concentration of 5000 mg/L, the percentage of dye removal was 59.44%. Comparing this result with that related to the sample with the same dye concentration but very low salt (60% dye removal) proves the continuous adaptation of microorganisms in salt concentrations of 5000 mg/L.

According to Reid's findings, microorganisms can adapt and survive in specific amounts of salt increasing (up to 5000 mg/L) by aggregating their cells and through physiological changes (Reid, Liu, & Judd, 2006).

The results of a research related to saline shock on activated sludge indicated that the tolerance threshold in activated sludge microorganisms is different when they encounter saline wastewater; some of them resist salt concentrations up to 5000 mg/L and some of them up to 10,000 mg/L (Salvadó et al., 2001).

Main changes happened in treatment efficiency when the TDS concentration of the synthetic wastewater increased to 10,000 mg/L. As seen in Figure 2, increasing the concentration of TDS led to an increase in COD concentration in wastewater and decreased COD removal efficiency to 14.92%.

In a study about the biological treatment of tannery wastewater using activated sludge microorganisms, a reduction in COD and BOD removal efficiencies became obvious when the biological treatment process took place in salt concentrations higher than 8000 mg/L (Sivaprakasam, Mahadevan, Sekar, & Rajakumar, 2008).

In real textile wastewater with a TDS concentration of about 1500 mg/L, the dye removal percentage obtained (73.86%) was as expected.

Again, in the last sample with a TDS concentration increased to 10,000 mg/L, the COD concentration increased in the treated wastewater; thus, the COD removal percentage, which was 18.33%, decreased, contrary to the similar sample with low salt concentration (real textile wastewater).

According to Reid's study on the effects of high salinity on activated sludge systems and membrane permeability, if the salt concentration in raw wastewater increases to more than 5000 mg/L, saline shock occurs in the biological treatment system and causes turbidity. As a result, colloidal material and suspended matter increase turbidity which is positively related to chloride levels as well as protein. An increase in TDS concentration causes increased protein solubility in biological systems; on the other hand, protein increases the floc's negative surface charge which leads to a decrease in mechanical strength between the flocs, and so increases colloidal material (Reid et al., 2006).

As stated in different reports, saline shock refers to increasing salt concentrations more than 5000 mg/L which affects COD and BOD removal as well as sludge coagulation properties and settlement. When a biological treatment system is used for wastewater with high salinity, the reason for decreasing COD removal is plasmolysis of the bacterial cells under the effects of salt, which leads to their loss of activity. Therefore, it can directly affect treatment efficiency (Kargi & Dincer, 1996).

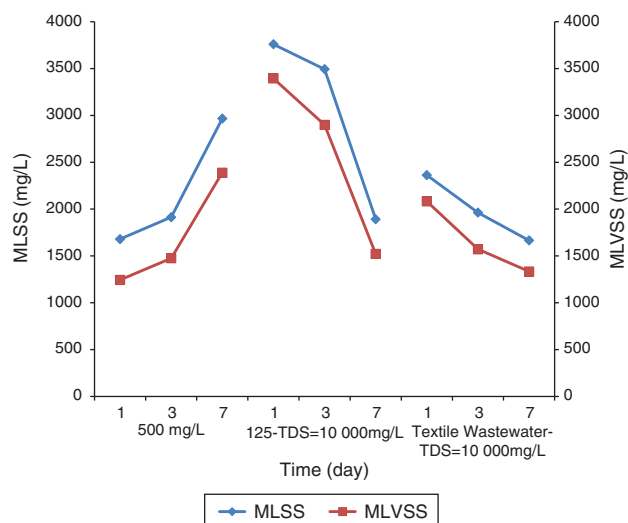


Fig. 3. Changes in MLSS and MLVSS concentrations during the treatment of 3 samples: 1 – synthetic wastewater containing a dye concentration of 500 mg/L and low salt; 2 – synthetic wastewater containing a dye concentration of 125 mg/L and TDS concentration of 10,000 mg/L; 3 – real textile wastewater with a TDS concentration of 10,000 mg/L. 500 mg/L: synthetic wastewater with dye concentration of 500 mg/L; 125-TDS = 10,000 mg/L: synthetic wastewater with dye concentration of 125 mg/L and TDS concentration of 10,000 mg/L; Textile Wastewater-TDS = 10,000 mg/L: real wastewater from textile factory with TDS concentration of 10,000 mg/L; MLSS: mixed liquor suspended solids; MLVSS: mixed liquor volatile suspended solids.

It has also been proven that high concentrations of NaCl in an activated sludge system cause the destruction of the microorganisms' cell walls and, eventually, disorder in the biological treatment (Hamoda & Al-Attar, 1995).

In the present research, the microorganisms adapted, and so COD removal continued at TDS concentrations of 1000 mg/L and even 5000 mg/L. However, a very small change occurred in COD removal when the TDS concentration of raw wastewater was raised to 5000 mg/L; this level of salt concentration represents the starting point of alternations in the function of activated sludge microorganisms.

3.2. MLSS and MLVSS parameters

To evaluate the microbial population and growth of activated sludge microorganisms, MLSS and MLVSS concentrations were measured throughout the 7 days of treatment. The results for the three selected samples ((500 mg/L), (125-TDS = 10,000 mg/L), and (Textile Wastewater-TDS = 10,000 mg/L)) are given in Figure 3.

In this figure, the graph related to synthetic wastewater with a dye concentration of 500 mg/L and COD concentration of 448 mg/L (in raw wastewater) represents the appropriate living conditions for microorganisms, because the graph is ascending (microbial population has grown). High efficiency has been reported for COD removal (80.71%) in this concentration. Microorganisms of activated sludge degrade the dyes by producing many enzymes such as laccase, manganese peroxidase, among others. Manganese peroxidase is capable of decoloring Remazol Brilliant Blue R. Therefore, under aerobic

conditions the microorganisms change dyes to organic materials and water. It leads to an increase of MLSS and, as a result, an increase of dye degradation by more microbial biomass (Gowri, Vijayaraghavan, & Meenambigai, 2014).

The descending procedure of MLSS and MLVSS graph for synthetic wastewater with a dye concentration of 125 mg/L, TDS concentration of 10,000 mg/L, and COD concentration of 134 mg/L indicates that increasing the salt concentration caused the microorganism population to decrease over 7 days.

As mentioned, the changing characteristics of the sludge which was treating the wastewater and the decreasing microorganism population are conditions that arise from high salinity (especially levels over 5000 mg/L).

In the third sample, the MLSS and MLVSS concentrations are related to the real textile wastewater sample with a TDS concentration of 10,000 mg/L that represents a decreasing microorganism population during the treatment days.

Results indicated that high salt concentrations lead to unavoidable impacts on MLSS concentrations as a result of changes in the characteristics of activated sludge (Reid et al., 2006).

3.3. pH parameter

Studying dye removal efficiency when the pH of the samples was changed was one objective of this research. According to Table 2, for wastewater with a dye concentration of 125 mg/L and a TDS concentration of 5000 mg/L and real textile wastewater, the treating processes were accomplished in a pH range of 7.5–8.5 for the first sample and 6.5–7.5 for the second sample during treatment days. The results showed no significant changes in the absorption amounts and COD removal efficiencies in the days that pH changes were applied; the reason for this is related to the range of microorganism activity with regard to the environment pH.

According to different resources, the optimum pH for an activated sludge system is 6.50–8.50 (Kalmi, Parshetti, Jadhav, & Govindwar, 2007; Ogugbue & Sawidis, 2011; Rao & Prasad, 2010). Microorganisms try to maintain their environmental pH near a neutral range by consuming energy. They have a special external structure which protects them. The minimum to maximum pH resistance range in activated sludge microorganisms is 6.50–8.50 (Barati, 2007).

4. Conclusions

The main purpose of this study was to investigate the ability of aerobic microorganisms of an SBR treatment system to remove COD from high saline textile wastewater. The activated sludge microorganisms could tolerate high salt concentrations and remove 60% of Brilliant Blue R dye from wastewater at a TDS concentration of 5000 mg/L; thus, SBR as a cost effective treatment system can be used for decolorization of textile wastewater even in saline conditions.

Conflict of interest

The authors have no conflicts of interest to declare.

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