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The Decolorization of Azo Dye Reactive Black 5 in a Sequential Anaerobic-Aerobic System

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Abstract

The potential of the sequential anaerobic-aerobic system for decolorization of azo dye Reactive Black 5 (RB 5) was investigated in this study. The synthetic wastewater contained 150 mg/L dye and 3000 mg/L glucose-COD. An upflow anaerobic sludge blanket (UASB) reactor and continuously stirred aerobic reactors (CSAR) were used to the remove color and COD. The methane gas production efficiencies were also investigated under the anaerobic conditions. The UASB - CSAR were operated at different organic loading rates (OLR= 2.4-22.5 kg COD/m^3.day) and hydraulic retention times (HRT= 3.2-30.1 h). The COD removal efficiencies decreased from 61 to 36.7% with increases in organic loadings from 2.4 to 22.5 kg COD/m^3.day in the anaerobic UASB reactor. The color removals decrease from 99.8 to 90.7% when the HRT decreased from 30.1 to 3.2 hours. The methane production efficiencies obtained were 75 and 38.3% at the organic loading rates of 2.4 and 22.5 kg COD/m^3.day respectively, in the anaerobic reactor. The effects of both sludge retention times (SRT) and the food to mass (F/M) ratio on the COD removal efficiencies was investigated in the aerobic reactor. COD removal efficiencies of 62.2 and 86.3% were obtained at 2 and 19 days SRT in the aerobic reactor. The COD removal efficiencies were found to be 86.3 and 62.2% at F/M ratios of 0.112 and 1.569 kgCOD/kgMLSS.day. The color and COD removal efficiencies obtained were 99.8% and 95% by using 150 mg/L of RB 5 dye concentration in the sequential anaerobic-aerobic reactor.

Keywords: Azo dye, decolorization, efficiency, Reactive Black 5, sequential anaerobic-aerobic system.

Ardışık Anaerobik - Aerobik Sistemde Reaktif Siyah 5 Azo Boyasının Renk Giderimi

Özet

Bu çalışmada, Raeaktif Siyah 5 (RB 5) azo boyasının renk giderimi için ardışık anaerobik-aerobik sistemin potansiyeli araştırılmıştır. Sentetik atıksu 150 mg/L boya ve 3000 mg/L glikoz-KOİ içermiştir. Renk ve KOİ giderimi için sürekli beslemeli anaerobik yukarı akışlı çamur yatak reaktör (YAÇYR) - sürekli karıştırmalı aerobik reaktör (SKAR) ardışık sistem kullanılmıştır. Ayrıca, anaerobik şartlar altındaki metan gaz üretim verimi belirlenmiştir. YAÇYR-SKAR reaktörlerde farklı organik yükleme oranı (OYO = 2.4-22.5 kg KOİ/m^3.gün) ve hidrolik bekleme süresinde (HBS = 3.2-30.1 saat) işletilmiştir. Anaerobik (YAÇYR) reaktörde organik yükleme oranı 2.4 kg COD/m3.gün'den 22.5 kg COD/m^3.gün'e yükselmesi ile KOİ giderim verimleri, % 61'den % 36.7'ye azalmıştır. HBS 30.1 saat'ten 3.2 saat'e düşürüldüğünde renk giderimi % 99.8'den % 90.7'ye düşmüştür. Anaerobik reaktörde 2.4 ve 22.5 kg KOİ/m^3.gün'lük organik yükleme oranında metan üretim verimleri sırası ile % 75 ve % 38.3 olarak elde edilmiştir. Aerobik reaktörde KOİ giderimi üzerine hem çamur yaşının (ÇBS) hem de besin maddesinin mikroorganizmaya oranının (F/M) etkisi araştırılmıştır. Aerobik reaktörde 2 ve 19 günlük ÇBS'de sırası ile KOİ giderim verimi %62.2 ve %86.3 olarak elde edilmiştir. F/M oranlarının 0.112 ve 1.569 kg KOİ kg MLSS/gün olduğunda KOİ giderim verimi %86.3 ve %62.2 bulunmuştur. Ardışık anaerobik-aerobik reaktörde 150 mg/L RB 5 boya konsantrasyonu kullanıldığında renk ve KOİ giderimi %99.8 ve %95 olarak elde edilmiştir.

Anahtar Kelimeler: Ardışık anaerobik-aerobik sistem, azo boya, Reaktif siyah 5, renksizleştirme, verim.

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INTRODUCTION

The discharge of highly colored wastewater is currently an important environmental problem. Synthetic dyes are extensively used in textile, paper, and printing industries, as well as in dye houses (Claus et al. 2002), because of their ease of production, fastness, and variety of colors compared with natural dyes (Mendez-Paz et al. 2005, Khehra et al. 2006). Over 100,000 commercially available dyes exist and more than 700,000 tons of dyes are manufactured worldwide annually (Hao et al. 2000). Azo dyes are the largest group of dyes used in the

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textile industry (Maximo et al. 2003), constituting 60-70% of all dyes produced (Carliell et al. 1995). They have become a concern in wastewater treatment because of their color, bio-recalcitrance, and potential toxicity to animals and humans (Yoo et al. 2000).

Various chemical, physical, and biological techniques may be employed for the decolorization of dyes found in wastewater but, each method has technical and economic limitations (Vandevivere and Bianchi 1998, Robinson et al. 2001, Demiral et al. 2008,). Many physicochemical decolorization methods are not suitable because they are expensive, have restricted usage areas, interfere with other wastewater components, or cause wastes that require retreatment. The biologic treatment method is an alternative to the physicochemical methods which is relatively inexpensive and may be preferred for decolorization (van der Zee and Villaverde 2005).

Anaerobic treatment may be a feasible alternative to treat textile wastewater especially in the case of azo dyes. In most cases, the dyes are easily reduced under anaerobic conditions (Carliell et al. 1995, van der Zee et al. 2001). The main disadvantage of azo dye reduction under anaerobic conditions is the production of aromatic amines, which usually do not degrade under these conditions (Mendez-Paz et al. 2005, Razo-Flores et al. 1996) and tend to accumulate at toxic levels (Carliell et al. 1995, Gottlieb et al. 2003). Such amines, however, are reported to be readily bio-transformed under aerobic conditions (Tan et al. 2000, Işık and Sponza 2004).

In a study performed by Sponza and Isık (2002), color and COD removal efficiencies were investigated using anaerobic - aerobic sequential processing for treatment of 100 mg/L of di-azo dye. Color removal efficiencies of 96% were obtained when glucose was used as the carbon source. Supaka et al. (2004) obtained 78.2% color removal and 90% COD removal in a sequential anaerobic - aerobic system that was used to treat Remozal Black B dye. Isık and Sponza (2004) reported 92.3 and 95.3% color and COD removal efficiencies, respectively, when using an upflow anaerobic sludge blanket (UASB)-aerobic stirred tank reactor (CSTR) sequential system to treat Congo Red dye. In a study performed by Kapdan and Oztekin (2006), over 90% color and more than 85% COD removal efficiencies were obtained in an anaerobic/aerobic SBR system (HRT= 2-19 h) that degraded Remozal Rot dye at a COD concentration of 500 mg/L. Khehra et al. (2006) observed 98 and 95% color and COD removal efficiencies respectively, in an anoxic-aerobic sequential bioreactor system used to treat Acid Red 88 azo dye. Zaoyan et al. (1992) obtained 65% color and 74% COD removal efficiencies in textile wastewaters contaminated with azo dyes using an anaerobic-aerobic rotating biodisc system at an HRT of about 8 hour and an organic loading rate of 45 g COD/m^3. day.

In the light of these facts, a sequential anaerobic-aerobic system was designed for the decolorization and degradation of Reactive Black 5, a commonly used textile dye.

MATERIALS AND METHODS

Dyes and chemicals

The azo dye Reactive Black 5 (RB5) was chosen as a refractory model pollutants and obtained from Kucuker Co. Textile Industry, Denizli, Turkey. This dye was particularly selected for this study since it is been commercially important and commonly used in the textile industries for the dyeing of cotton, woolen, and nylon fabrics worldwide as well as in Turkey (Table 1). All the chemical compounds used to prepare the reagent solutions were of analytic reagent grade (Merck and Sigma).

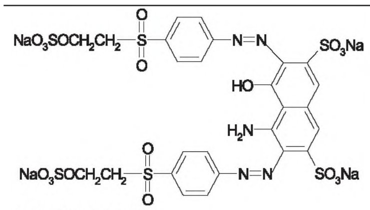
Composition of synthetic dye wastewater

The basic composition of the synthetic dye wastewater contained azo dye at 150 mg/L. The growth media was made of NH_4Cl, 400; $MgSO_4{\cdot}7H_2O$, 400; KCl, 400; $Na_2S{\cdot}9H_2O$, 300; $(NH_4)2HPO_4$, 80; $CaCl_2{\cdot}2H_2O$, 50; $FeCl_3{\cdot}4H_2O$, 40; $CoCl_2{\cdot}6H_2O$, 10; KI, 10; $(NaPO_3)_6$, 10; l-cysteine, 10; $AlCl_3{\cdot}6H_2O$, 0.5; $MnCl_2{\cdot}4H_2O$, 0.5; $CuCl_2$, 0.5; $ZnCl_2$, 0.5; NH_4VO_3, 0.5; $NaMoO_4{\cdot}2H_2O$, 0.5; H_3BO_3, 0.5; $NiCl_2{\cdot}6H_2O$, 0.5; $NaWO_4{\cdot}2H_2O$, 0.5, and Na_2SeO_3, 0.5 (mg/L) (Speece 1996). The anaerobic conditions were maintained by adding 667 mg/L of sodium thioglycollate (0.067%) which has been proposed to provide anaerobic conditions between 0.01-0.2 percent (w/w). The alkalinity and pH were adjusted by adding 5,000 mg/L $NaHCO_3$. For COD, 3,000 mg/L of glucose was used as a co-substrate to provide reducing equivalents with electron fission.

Biomass

The granular anaerobic sludge used in the UASB was taken from the wastewater treatment reactor of the Frito Uzay Chips Industry in Izmir. The

Table 1. Characteristics of the azo dye

Open formulas	Maximum wavelength (nm)λ_{max}	COD value of dye at 1000 mg/L (mg/L)
 Reactive Black 5 C.I. 20505	598	782

activated sludge culture used in the CSAR was taken from Efes Pilsen, in Afyon, Turkey.

Experimental lab-scale sequential system

Continuously fed stainless steel anaerobic UASB and aerobic CSAR reactors were used in sequence for the experiments. The UASB reactor had 2.5 L of effective volume with an internal diameter of 6 cm and a height of 100 cm. The temperature was controlled at 35°C by a heating jacket. The CSAR reactor consisted of an aeration tank (working volume: 9 L) and a settling compartment (working volume: 1.4 L). The effluent of the anaerobic UASB reactor was used as the influent for the aerobic CSAR reactor.

The sludge retention time (SRT, θ_C) is the total quantity of active biomass in the reactor divided by the total quantity of active biomass withdrawn daily. Since no sludge wasting was applied for granule formation in the UASB reactor, θ_C in this reactor was determined using equations (1) and (2).

$$\theta_{CU} = \frac{V_U * X_U}{Q_{UW} * X_{UW} + Q_{UE} * X_{UE}} \quad (1)$$

The term $Q_{UW}*X_{UW}$ only makes sense if there is a waste sludge stream. Since there is no sludge wastage in the UASB reactor, θ_{CU} can be expressed as follows:

$$\theta_{CU} = \frac{V_U * X_U}{Q_{UE} * X_{UE}} \quad (2)$$

Stepwise increases in organic loading cause increases in both flow rates (Q_{UE}) and microorganism concentrations in the effluent (X_{UE}) of the UASB reactor. Therefore, θ_C in the UASB reactor was calculated on the basis of equation (2) and varied depending on the shock organic loading applied.

The sludge wasting in the CSTR reactor occurred from the aeration tank and the solids in the effluent (X_{CE}) were taken into consideration. Therefore θ_C in this reactor is adjusted by using equations (3) and (4).

$$\theta_{CC} = \frac{V_C * X_C}{Q_{CW} * X_{CW} + Q_{CE} * X_{CE}} \quad (3)$$

Since the activated sludge was withdrawn from the inside of the aeration stage, the microorganism concentration in the reactor (X_C) was equal to the wasted microorganism concentration (X_{CW}). If XCE is negligible, equation (4) was used to calculate the θ_C in CSTR reactor.

$$\theta_{CC} = \frac{V_C}{Q_{CW}} \quad (4)$$

Analytical methods

Volatile suspended solids (VSS), total suspended solids (TSS), mixed liquor suspended solids (MLSS), and mixed volatile suspended solids (MLVSS) were measured using standard methods (Anonymous 1989). The COD was analyzed using a UV visible spectrophotometer (Dr Lange, Cadas 200, Germany). Gas production was measured by the liquid displacement method. The total gas produced was measured by passing the gas through distilled water containing 2% (v/v) H_2SO_4 and 10% (w/v) NaCl (Beydilli et al. 1998). Methane gas was detected by using 3% NaOH (w/v) containing distilled water (Razo-Flores et al. 1997). The total volatile fatty acid (TVFA) concentrations and bicarbonate alkalinity (B.Alk.) in the effluent of the UASB reactor was measured by using the titrimetric Anderson and Yang (1992) method with a computer. Oxidation reduction potential (ORP), pH, dissolved oxygen (DO) and temperature were measured by using a digital ion analyzer with combination electrodes (Multi 340i, WTW, Germany).

Color density and UV-Vis spectra of the RB5 were recorded from 200 to 800 nm wavelengths using a UV/Vis spectrophotometer (Dr Lange, Cadas 200, Germany). The samples were centrifuged at 7,000 rpm for 10 min (Hettich EBA III model) and the absorbance values of the supernatants were measured (Table 1). The maximum absorbance wavelength (λ_{max}) of RB5 was found at 598 nm (Karataş and Dursun 2007). Color removal efficiencies after anaerobic treatment were calculated using the formula as follow:

$$CR(\%) = \frac{Do - D}{Do} * 100 \quad (5)$$

where D_0 and D are concentrations of dye before and after anaerobic treatment in mg/L respectively.

Operating conditions

Before mixing dye solutions with the synthetic wastewater containing Vanderbilt minerals, we activated the anaerobic sludge for 30 day with an HRT of 17.85 hours with the concentration of 3000 mg/L glucose and 5000 mg/L $NaHCO_3$. The studies were carried out in a continuous mode and the effluent of the UASB reactor was used as feed for the CSAR reactor. After a COD removal of 60% and a methane production of 68% were obtained at the end of the 30 day period, the sequential anaerobic-aerobic system was loaded with the Reactive Black 5 dye (150 mg/L). The HRT changed between 3.2 and 30.1 hours in the UASB reactor and changed between 0.5 and 4.5 days in the CSAR reactor. The HRT was obtained as different values for the UASB and CSAR because of the different reactor volumes. The SRT changed between 2 and 19 days in the CSAR reactor. The flow rates were changed for regulating the SRT values (Eq.4). The dye concentration of the textile industries varies from 10 to 200 mg/L according to literature and technical reports (Alaton et al. 2008, Lucas et al. 2007, O'Neill et al. 1999). It was also reported and known that the more concentrated the dye was the more difficult was to treat. Therefore, an RB5 concentration of 150 mg/L was selected for this study. The experimental parameters are presented in Table 2.

RESULTS AND DISCUSSION

An upflow anaerobic sludge blanket (UASB) and continuously stirred aerobic (CSAR) reactor were used to treat wastewater that contained RB 5 dye. The effect on the color and COD removal by modifying parameters including variable hydraulic retention time (HRT), organic loading, sludge retention time (SRT), and food to mass (F/M) ratio was investigated.

Color and COD removal in a UASB reactor

To determine the HRT in the UASB reactor, the color and COD removal were investigated by adding 150 mg/L RB 5 dye at an HRT varying between 3.2 and 30.12 hours. The effect of HRT at different anaerobic stages on the color and COD removal efficiency is shown in Figure 1. At 30.12 hour HRT, 99.8% color and 61% COD removal efficiencies were obtained. The COD removal decreased with the decrease of HRT, but, color removal did not change considerably. The color removal efficiency obtained from the HRT varied between 10.68 and 30.12 was greater than 98%. The color removal efficiency was 90.7%, and the COD removal efficiency was 36.7% in the anaerobic system operated at a hydraulic retention time of 3.2 hours.

A consequence of performing the measurements on the effluent of the UASB reactor at the 30.12 hour HRT was that the dye concentration decreased to 0.3 mg/L. The effluent dye concentration was determined as 13.9 mg/L, while the HRT was 3.2 hours. COD concentrations decreased from 2003 mg/L to 1237 mg/L with the increasing of HRT from 3.2 to 30.12 hours, respectively (Figure 2).

The effect of organic loading on gas production and TVFA/B.Alk. ratio in a UASB reactor

The dye load also changed in the anaerobic reactor depending on the variation in HRT. When the HRT was decreased from 30.12 to 3.2, the dye load increased from 4.98 g/m^3h to 46.88 g/m^3h. As seen at Figure 3, with an increase of dye load from 4.98 g/m^3h to 46.88 g/m^3h, the COD removal decreased from 61% to 36.7%. Depending upon the increase in the dye load, the color removal efficiency decreased from 99.8% to 90.7%. It was concluded from this result that color removal was negatively affected by dye load.

The methane production percentage decreased with the increase of organic loading (Figure 4). The acidification phase was more active while the organic loading was high. This may be because of the negative effect of the high organic load on the activity of methane forming bacteria. The methane production in the anaerobic reactor obtained was 75%, 62.5%, and 38.3% while the organic load was 2.4, 9.1, and 22.5 $kgCOD/m^3$.day, respectively. Volumetric methane productions were 544, 281, and 116 mL/day for the above mentioned organic loads, respectively. It was also concluded from this study that volatile fatty acids could not completely transformed to methane by the methane bacteria, depending on the increase in the organic loading.

The VFA/B.Alk. ratio increased to 0.79 from 0.67 when the organic load increased from 2.4 $kgCOD/m^3$.day to 22.5 $kgCOD/m^3$.day. An increase in the VFA/B.Alk. ratio indicated that the acid producing bacteria in the reactor were more active.

Table 2. The operating parameters and conditions in the anaerobic and aerobic reactors

	Period (days)	HRT (Θ_H) *	Organic loading (kgCOD/m³.day)	F/M ratio (kgCOD/kgMLSS.day)	SRT(Θ_c) (day)	ORP (mV)	DO (mg/L)	Dye loading (g dye/m³.h)
Anaerobic (UASB) reactor								
Start up	0 - 30	17,85	4,03	0,187	44	-329	0,1	-
Run 1	31 – 46	30,12	2,40	0,126	38	-378	0,1	4,98
Run 2	47 – 58	17,85	4,03	0,203	30	-320	0,1	8,40
Run 3	59 – 67	10,68	6,74	0,331	18	-365	0,1	14,05
Run 4	68 – 74	7,92	9,10	0,453	13	-383	0,1	18,95
Run 5	75 - 80	5,62	12,80	0,629	9	-391	0,1	26,68
Run 6	81 - 84	3,20	22,5	1,107	5	-408	0,1	46,88
Aerobic (CSAR) reactor								
Start up	0 - 30	2,68	0,46	0,168	18	154	2,7	
Run 1	31 – 46	4,5	0,27	0,100	19	121	2,4	
Run 2	47 – 58	2,68	0,64	0,227	11	115	2,1	
Run 3	59 – 67	1,60	1,15	0,392	7	109	1,9	
Run 4	68 – 74	1,19	1,62	0,492	5	101	1,7	
Run 5	75 - 80	0,84	2,28	0,707	4	97	1,6	
Run 6	81 - 84	0,48	4,17	1,320	2	85	1,5	

*, Unit for HRT: hours for anaerobic reactor but days for aerobic reactor and system.

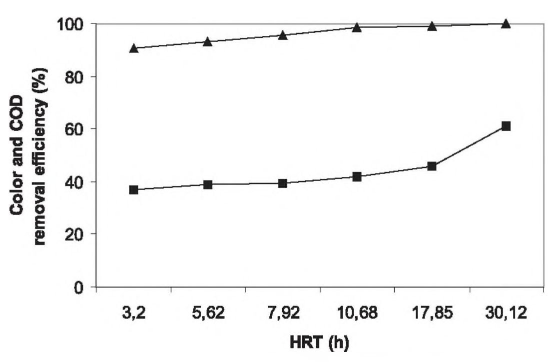


Fig 1. The effect of HRT on the color and COD removal of the UASB reactor using synthetic textile dye wastewater treatment.

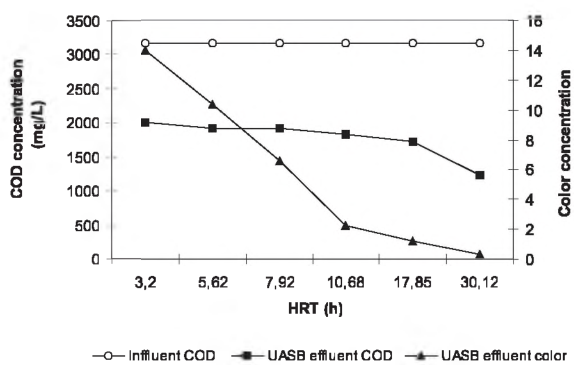


Fig 2. The effluent COD and dye concentrations versus HRT of the UASB reactor during synthetic textile dye wastewater treatment.

When the VFA/ B.Alk. ratio was smaller than 0.4, the reactor was stable; when the ratio was between 0.4 and 0.8, the reactor was moderately stable, and when it was greater than 0.8, the reactor was unstable (Behling et al. 1997). As shown in Fig. 4 this ratio varied between 0.67 and 0.79, indicating the high VFA concentrations at high organic loading because of high COD and dye concentrations in the reactor. The volatile fatty acids formed in the reactor and depending on the increase of dye and organic loading caused the anaerobic reactor to be unstable. Although the formation of acidogenic conditions in the reactor had a negative effect on the COD removal, it did not affect the color removal. It was

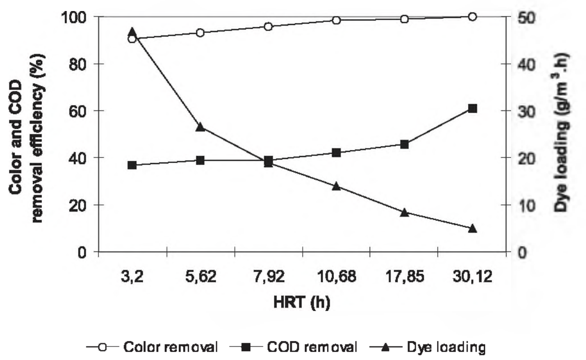


Fig 3. The effect of change of the dye load, which is dependent upon HRT, on the color, and COD removal of the UASB reactor during synthetic textile dye wastewater treatment.

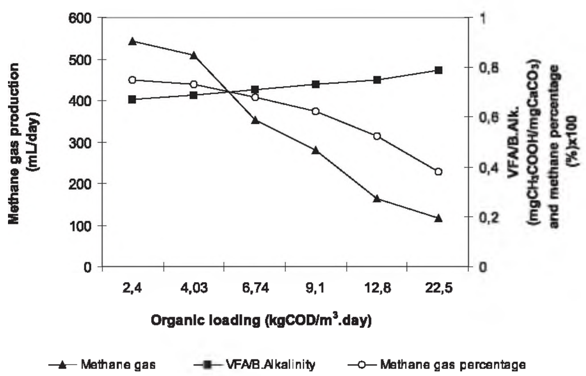


Fig 4. The effect of organic loading on the gas produced, methane percentage, and VFA/ B.Alk. ratio of the UASB reactor during synthetic textile dye wastewater treatment.

seen in literature that the acid producing bacteria also contributed to color removal (Chinwetkit-vanich et al. 2000).

The effect of HRT and F/M ratio in the CSAR reactor

The COD concentrations in the influent CSAR reactor decreased from 2003 mg/L to 1237 mg/L with the increasing of HRT from 3.2 to 30.12 hours, respectively. Figure 5 shows that the highest COD removal efficiency obtained was 84.2% for the 4.5 day HRT. When the HRT of the CSAR reactor decreased from 4.5 days to 0.48 day, the removal efficiency of the COD decreased from 84.2% to 55%. COD concentration at the CSAR reactor effluent decreased to 196 mg/L for the 4.5 day HRT. The effluent COD concentration was 901 mg/L for the lowest HRT (0.48 day).

The effect of organic load and F/M ratio on the COD removal in the aerobic reactor is shown in Figure 6. When the F/M ratios were increased from

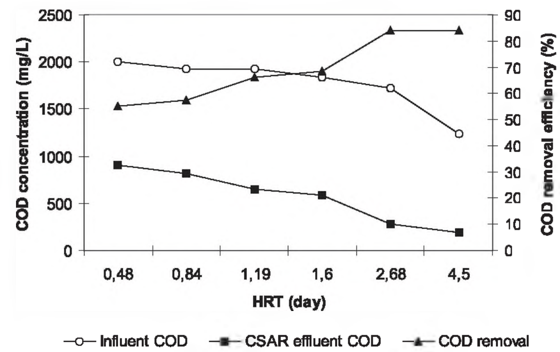


Fig 5. The variation of COD removal and COD concentration with increasing HRT in the CSAR reactor during synthetic textile dye wastewater t reatment.

0.115 to 1.569 kg COD/kgMLSS.day, the COD removal decreased from 84.2% to 65 %, respectively. Similarly, in the high organic loadings, low COD removal efficiencies were obtained. The COD removal efficiencies were 84.2%, 68.3%, and 55% when the organic loadings were 0.32, 1.36, and 4.96 kgCOD/m^3.day, respectively.

The effect of SRT on COD removal in the CSAR reactor

COD removal efficiencies increased from 55 % to 84 % when the SRT was increased from 2 days to 11 days. The COD removal efficiency of the aerobic reactor increased remarkably with increasing SRT values up to 11 days, and then the increase rate was slower until the 19 day (84.2%). These results suggest that the 11 days was the optimum SRT for the activity of the microorganisms (Figure 7). Similar studies (Lourenço et al. 2000, Psukmhun and Vinitnantharat 2003) have obtained high COD removal efficiencies at 12 and 15 days of SRT.

The changes of MLSS, MLVSS, and SVI parameters versus experimental stages are shown in Figure 8. The ratio of MLVSS/MLSS obtained was between 0.76 and 0.89 when the SVI varied between 55 mL/g and 117 mL/g. Ong et al. (2005) stated that, the most suitable conditions were formed for the aerobic reactor when the SVI was between 45 mL/g and 110 mL/g.

The color and COD removals in the UASB-CSAR sequential system

In the sequential UASB-CSAR reactor system, the color and COD removal efficiencies increased from 91 and 72 to 99 and 91 when increasing the HRT from 0.61 days to 3.42 days, and then the increase rate was slower until the 5.76 day (99.8%

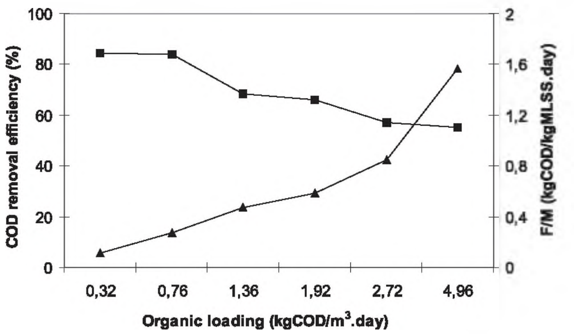


Fig 6. The effect of organic loading variation on the F/M ratio and COD removal efficiency in the CSAR reactor

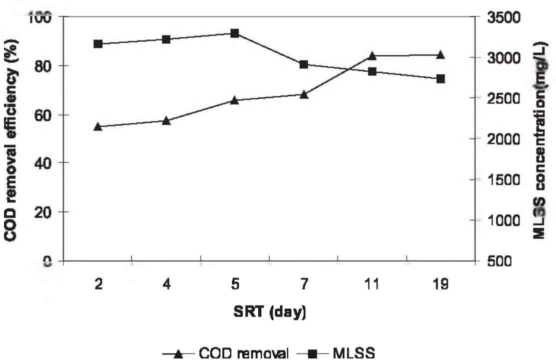


Fig 7. The effect of sludge retention time (SRT) and mixed liquor suspended solids (MLSS) concentration on the COD removal in the CSAR reactor during synthetic textile dye wastewater treatment.

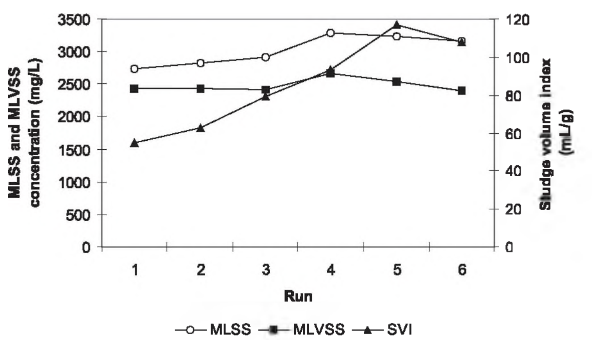


Fig 8. The variation of the sludge volume index (SVI) with mix liquor suspended solids (MLSS) concentration and mixed liquor volatile suspended solids (MLVSS) concentration versus experimental stage time in the CSAR reactor during synthetic textile dye wastewater treatment.

and 94 %), respectively. These results suggest that 3.42 days was the optimum HRT for the maximum removal efficiency (Figure 9).

The color removal varied between 99.8% and 91%, and the COD removal varied between 94% and 71% throughout the 53 days experimental

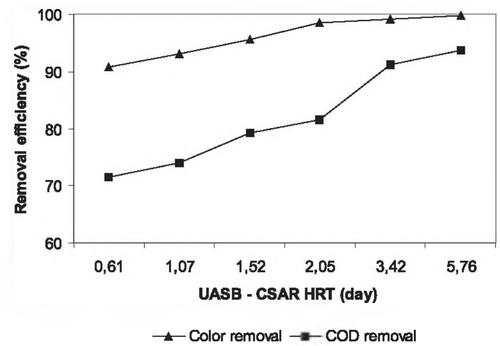


Fig 9. The effect of the sequential anaerobic-aerobic system HRT on the color and COD removal during synthetic textile dye wastewater treatment.

incubation period in the sequential system.

CONCLUSIONS

This paper presented the results of a detailed study of the sequential anaerobic-aerobic treatment system that removed RB5 from a synthetic dye wastewater using a mixed culture of microorganisms. The optimum removal efficiencies were 99% for color and 91% for COD at 3.42 days HRT in the sequential anaerobic-aerobic system. Operational parameters such as the HRT, OLR, VFA/B.Alk. ratio, F/M ratio, SRT, and SVI all clearly affected the removal efficiency. The aerobic reactor removed 90% of the COD that could not be removed by the anaerobic reactor. This may be due to aromatic amines, which usually do not degrade under anaerobic conditions but readily bio-transformed under aerobic conditions.

The results of this paper provide a good indication of the different operating conditions that would be required for efficient removal of RB5 from dye wastewater and also indicated that the sequential anaerobic-aerobic treatment system enables us to meet the energy needs of industry with the methane gas produced in the anaerobic system.

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