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Biodegradation of COD from wool processing plant effluent utilizing low-cost sequencing batch reactor

Wan Nur Sakinah Din, Fathurrahman Lananan, Siti Hajar Abdul Hamid, Ahmad Jusoh*

School of Ocean Engineering, Universiti Malaysia Terengganu, Kuala Terengganu 21030, Malaysia, emails: gsk1159@pps.umt.edu.my (W.N.S. Din), gsk1147@pps.umt.edu.my (F. Lananan), gsk1423@pps.umt.edu.my (S.H.A. Hamid), ahmadj@umt.edu.my (A. Jusoh)

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ABSTRACT

The processing of wool fibre were carried out in accordance with the standard production quality which emphasized on shrink-proof and increased washability by the changing the wools' physical properties. Commonly, the properties alterations were based on the use of chemicals. This explained the high amount of chemical oxygen demand (COD) content of 1441 ± 26.58 mg/L present in the plant effluent. Hence, this study was carried out to investigate the COD biodegradation utilizing activated sludge cultured in sequencing batch reactor (SBR). A step-by-step feeding approach was chosen during the acclimatization phase to allow gradual adaptation of the bacteria in activated sludge prior to the introduction to the actual concentration of the plant wastewater. Subsequently, the effect of the inoculation of effective micro-organism (EM) at various volumetric loading ratio of wastewater to activated sludge was also investigated. During acclimatization, the outcome of 87–92% of COD removal was achieved. Results showed that the volumetric loading ratio of 1.2 had 80% COD removal with the final concentration of 175 mg/L. In addition, it was found that EM significantly increased the COD biodegradation rates of SBR.

Keywords: Biodegradation; Wool-processing wastewater; Activated sludge; SBR; COD biodegradation

1. Introduction

Wool as an important raw material for the textile industry was produced by over 100 countries worldwide. In its simplest term, wool is a fibrous protein which is highly favoured by the users due to its good qualities and services properties. Wool has an excellent flexibility, good warmth retention, high hygroscopicity, adequate static and stain resistance, tender lustre, soft handle and a higher igniting temperature than most of conventional fibres [1–3]. Wool as a high-quality protein fibre has been widely used as high-quality fabrics in textile industry such as clothing material for various characteristics. It was even used as technical textile such as in automotive,

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*Corresponding author.

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aerospace, medical and decoration fields [1–3]. Freshly shorn wool contains three main contaminants which are wool grease, suint and dirt [4].

Before the raw wool was turned to wool top which is a semi-processed product, several mechanical processes involved. The common processes were carding, scouring, gilling, combing and finishing gilling. Most of the wool grease and other contaminants were removed by the scouring process before any further processing can be carried out [5–9]. Scoured wool processing produced a very strong flow of effluent, and a highly effective treatment approach is needed to avoid negative impact to the environment [6,7,9]. Various treatments have been developed, generally based on biological, chemical, physicochemical or a combination between them [7,10].

Major disadvantage of wool is its felting tendency during the washing process. In wool top-making industry, the wool is treated by changing its properties using several methods to induce shrinkproofing and washability [11]. The most effective method in wool treatment is the chlorine–Hercosett shrinkproofing process which is also known as superwash [12]. Superwash process uses highly concentrated acid chlorine to remove the scales on wool fibre surface and the subsequent polymer resin application for wool smoothing. Hence, the treatment process produces effluent contained highly concentrated chemical residue and dirt which contributes the high amount of chemical oxygen demand (COD) concentration.

Wastewater from wool top-making industry is harmful due to its washing process which mainly consists of chemicals and detergent. Effluent wastewater released is a significant environmental problem because it contains high COD concentration. Unprocessed wool is highly contaminated with organic matters such as sebum, body oil, sweat, dirt and mud which also contributed to the total COD amount in the wastewater effluent. This results in the release of COD which contain both organic and inorganic matter. The organic matter is readily degradable by biological treatment and natural micro-organism; however, through the addition of reagents in the superwash process in acidic condition, wastewater becomes heavily loaded with chemicals. In addition, the receiving water body could be affected due to the acidity and very low pH of wastewater effluent.

Sequencing batch reactor (SBR) is an activated sludge system which is widely adopted to treat industrial wastewater in textile industry [13–15]. The operation of SBR is in cyclic phase which consists of fill, react, settle, draw and idle [16]. Within a single reactor, the SBR performs the equalization, biodegradation and secondary clarification processes, thus, requires lesser space than the other type of treatment plant [13]. As compared to the various types of conventional biological wastewater treatment, SBR technology differs, especially in the operational condition [17]. Biodegradation process occurs in SBR simultaneously with the growth of micro-organism by consuming the contaminant in the wastewater.

The aim to this study was to explore the ability of activated sludge in treating wool processing wastewater. This approach was determined by the evaluation of the COD removal during the acclimatization phase. Specifically, the SBR performance on COD biodegradation was investigated by varying the volumetric loading ratio of the wastewater to activated sludge in SBR. In order to enhance the COD biodegradation of wool processing wastewater, EM was inoculated in SBR and the significance of the treatment efficiency was examined.

2. Materials and methods

2.1. Wastewater characterization

The wool processing wastewater was collected from the wool top-making factory located at Gong Badak Industrial Estate, Kuala Terengganu. The factory processed a scoured wool by utilizing two types of processing methods, which were backwash and superwash. The waste effluent streams from the combination of both processes were collected at the wastewater retention tank. Due to the acidic pH range of the wastewater (pH 2.13–2.27), the pH was neutralized by adding a 1 M solution of sodium hydroxide (NaOH) prior to the feeding to SBR. This was done in order to minimize any potential toxic or inhibitory effects on the growth of activated sludge [18]. The parameters considered in the determination of the characteristic of wool processing wastewater were temperature (*T*), dissolved oxygen (DO), pH, COD, biochemical oxygen demand (BOD_5), total suspended solid and turbidity.

2.2. Acclimatization of activated sludge for SBR and EM-SBR

The seed for the activated sludge was taken from the aeration tank of municipal sewage treatment plant operated by Indah Water Konsortium (IWK) located in Kuala Terengganu, Malaysia. Subsequently, the sludge was screened with a 425-μm sieve to eliminate large particles [19]. For EM-SBR, 2 ml of EM was inoculated into the activated sludge gradually during the aeration phase. In order to allow the activated sludge to be acclimatized with the wastewater condition, a step-by-step feeding approach was adapted from Fongsatitkul et al. [18]. During the acclimatization phase, each system was determined to achieve at least 80% of COD removal before the increase of operation volume by addition of 0.4 L of wastewater to each reactor. The incremental operation volume increase without any sludge wasting was repeated five times until the targeted operating volume was achieved.

2.3. Reactor set-up and operational condition

The reactor was fabricated using clear polycarbonate bottle with an operating volume of five litres for the laboratory-scale experiments. Six reactors were assembled from used polycarbonate bottle, where three replicates served function as SBR and another set as EM-SBR. Aeration was supplied using table-top air compressor into the reactor through a sparger which was located at the base of the reactor. Wastewater pumping was carried out using a Geyser pump which was connected to another table-top air compressor. All mixing and pumping processes relied on pneumatic technique and the configuration and timing sequence of the two air compressors to allow the fully operational and semi-automatic function of the SBR with the lowest cost of construction. During the reaction phase, vigorous aeration was utilized for homogeneous mixing of activated sludge and wastewater. Two effluent valves were installed on the SBR with the function of effluent withdraw and sludge wasting. The sludge wasting process was done at the end of the reaction phase to maintain the concentration of activated sludge inside the reactor. In overall, the total operating cycle was 24 h of hydraulic retention time (HRT) as reported by Mohan et al. [17]. The phases for each reactor consisted of 15 min of feeding (Fill), 22 h of aeration (Reaction), 1 h of settle down (Settle), 15 min of effluent discharge (Draw) and 30 min of idle time (Idle).

To study the performance of SBR with different volumetric loading ratio of wastewater to activated sludge, both reactors were inoculated with 1 L of acclimatized activated sludge. The treatment was initiated by introducing 0.5 L of wool processing wastewater into the reactor. Subsequently, the biodegradation of organic matter in the wastewater was determined by monitoring the COD removal and biomass growth. The effect of various volumetric loading ratio of wastewater to activated sludge on the COD removal percentage was studied by the increased of the volume of wastewater to 0.75, 1.0, 1.5, 2.0 and 3.0 L, respectively.

2.4. Analytical methods

Biomass concentration account in terms of mass liquor suspended (MLSS) and mass liquor volatile suspended solids (MLVSS) were measured according to the Standard Method for the Examination of Water and Wastewater [20]. An aliquot of 10 ml was taken at the end of each reaction phase and filtered through GF-C Whatman filter paper. Subsequently, the filtrate was subjected to MLSS and MLVSS analysis, while the residue was analysed for COD concentration. The determination of COD was analysed using the HACH reactor digestion method which was approved by the USEPA wastewater analysis. Two millilitres of sample were pippeted into the COD digestion vial and heated at 150°C for two hours in the COD digestion reactor block (HACH DRB 200). Finally, COD concentration was read using HACH DR2800 field spectrophotometer. Heavy metals (manganese, copper, lead, chromium, cadmium, zinc, nickel) were determined by inductively coupled plasma method according to APHA.

3. Results and discussion

3.1. Characteristic of wool processing effluent wastewater

Wool processing wastewater could be classified as polluted industrial wastewater effluent. A summary of

Table 1
Wool fibre processing wastewater characteristics of Nankai Nikke (M) Sdn. Bhd

Parameter	Value
Temperature (°C)	29.53 ± 0.07
COD (mg/L)	1441.323 ± 26.577
BOD_5 (mg/L)	308.122 ± 19.698
pH	2.20 ± 0.70
Dissolved oxygen (mg/L)	7.015 ± 0.171
Total suspended solid (mg/L)	310.423 ± 91.755
Total dissolved solid (g/L)	1.135 ± 0.074
Salinity (ppt)	0.876 ± 0.55
Ammonia nitrogen (mg/L)	0.78 ± 0.04
Turbidity (NTU)	317.321 ± 5.735
Heavy metals	
Manganese (Mn)	0.205 ± 0.043
Copper (Cu)	0.046 ± 0.007
Lead (Pb)	<0.010
Chromium (Cr)	<0.005
Cadmium (Cd)	<0.002
Zinc (Zn)	0.356 ± 0.078
Nickel (Ni)	0.006 ± 0.003

important effluent wastewater characteristics were represented in Table 1. Wool processing wastewater is highly acidic with pH value ranging from 2 to 2.3 which was mainly contributed by the reaction of chlorine gas with water producing concentrated hypochlorous acid. However, most biological treatment systems operate successfully only within neutral pH condition. At pH of 9.0 and above, microbial activity would be inhibited, whereas pH of less than 6.5 leads of higher fungi growth as compared to the reactor's beneficial bacterial growth. The presence of fungi growth within an activated sludge culture would lead to filamentous bulking problem [21].

Table 1 shows the COD concentration present in the wastewater effluent of wool processing industry. During the wool processing, the wool was washed in several continuous series of bowls which contained various chemical reagents which served different functions such as anti-shrink, whitening, softener and rinsing purposes. These processes contributed to high organic and inorganic matter loading and resulting in high COD concentration present in the wastewater effluent.

Fortunately, the heavy metal concentrations of the wastewater were in acceptable range as referred to the recommendation of the DOE (Table 1). In order to allow the growth of micro-organisms for the purpose of wastewater treatment, heavy metals concentration should be less than 1 mg/L to avoid the cytotoxic effect leading to the decline of bacteria cell growth.

3.2. Acclimatization phase

An acclimatization phase is required in order to allow the micro-organisms to gradually adapt with the inhibitory or toxic organic compounds present in the industrial wastewater. In fact, this step is vital for the production of the appropriate enzyme-producing genes which are crucial to induce biodegradation of the wastewater [22]. The selected microbial feeding strategy as described in Section 2.2 seemed to be successful since the COD removal was determined to be higher than 80% for all replicates during the acclimatization phase (see Fig. 1). Thus, the ability of domestic activated sludge to adapt with contaminant of wool processing wastewater is evidence. Although the biodegradability of wastewater as expressed by BOD_5 to COD ratio of 0.21 indicated as a slow rate, it managed to treat concentrated amount of organic matter removal in acclimatized phase. As reported, the non-easily biodegradable compounds in industrial wastewater were proved to be successfully removed by domestic activated sludge [15,23].

During the experiment, the growth of microbial biomass and COD removal was observed in the second batch of the acclimatization at the first 4 h of reaction phase. According to the treatment efficiency in 1 h of the reaction phase, EM-SBR achieved 81% removal percentage which is higher than the SBR at 77% of (Fig. 2). The addition of EM in the activated sludge culture contributed to the increased of the biomass concentration of about 16% and the improvement of the biodegradation of organic matter inside the wastewater.

In the first hour of the reaction phase, the substrate utilization was very high, however, the biomass growth had no relation with it due to its slow rate. This mainly explained by the maintenance processes which occurred within the activated sludge. A fraction of the substrate was used for the cell survival without any visible microbial growth. Rapid substrate reduction by the activated sludge showed the presence of readily biodegradable substrate as it was a source of energy for cell maintenance.

Subsequently, after absorbing enough substrate for the cell maintenance energy the microbial biomass growth increased exponentially. At this phase, the biomass reproduces new cell which contributed to higher biomass concentration. However, the removal rate for

Table 2
The experimental operation of the SBR and EM-SBR

Run	HRT (d)	Volumetric ratio (L/L)	OLR (g COD/L d)	COD removal (%)	
				SBR	EM-SBR
1	24	0.50	0.7	69.1	67.7
2	24	0.75	1.1	70.4	68.2
3	24	1.00	1.4	86.7	90.6
4	24	1.50	2.2	78.0	75.5
5	24	2.00	2.9	68.8	69.2
6	24	3.00	4.3	54.9	53.8

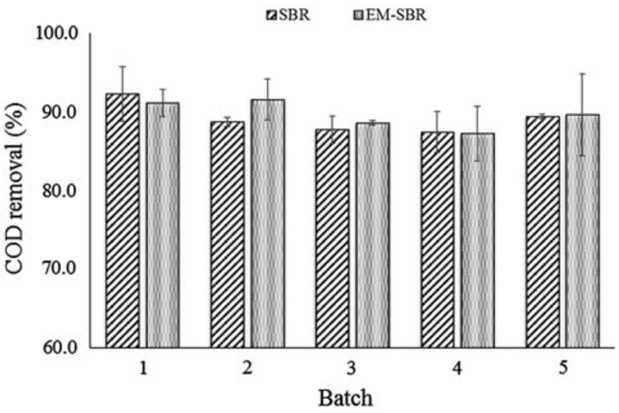

Fig. 1. COD removal fo SBR and EM-SBR during acclimatization.

the substrate was slower due to the consumption of maintenance energy within the non-growth condition.

After two hours of the reaction phase, the biomass growth started to decrease as the activated sludge entered the death phase. Due to the lower concentration of substrate for microbial community to consume, the bacteria cell competed for the availability of substrate. This is known as the starvation in aerobic condition. Since there are two types of substrate; degradable and non-degradable substrate, non-degradable substrate remained in the wastewater effluent since it was not absorbed.

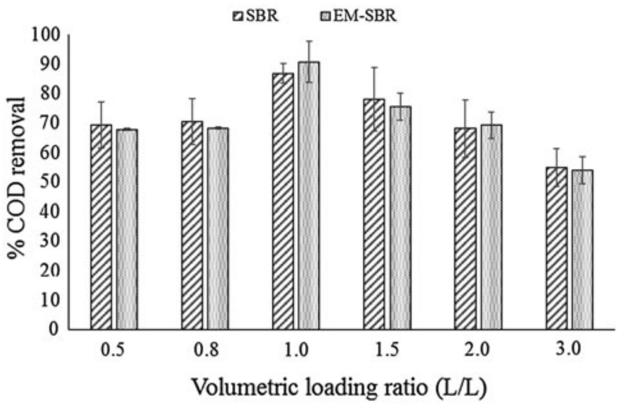

Fig. 3. COD removal efficiency as a function of volumetric loading ratio for SBR and EM-SBR.

3.3. Effect of volumetric ratio on COD biodegradation

In the experimental condition, the volumetric ratios were varied between 0.5 and 3.0 L/L in order to observe the COD removal efficiencies Table 2. The removal efficiency increases for about 17.6% COD removal for SBR at volumetric ratio of 0.5–1.0 L/L. For EM-SBR, the COD removal efficiency increase higher for about 22.9%. However, further increase of volumetric ratio did not contribute to the improvement in COD removal. Experimentally, as the volume of wastewater was added into SBR, the volume

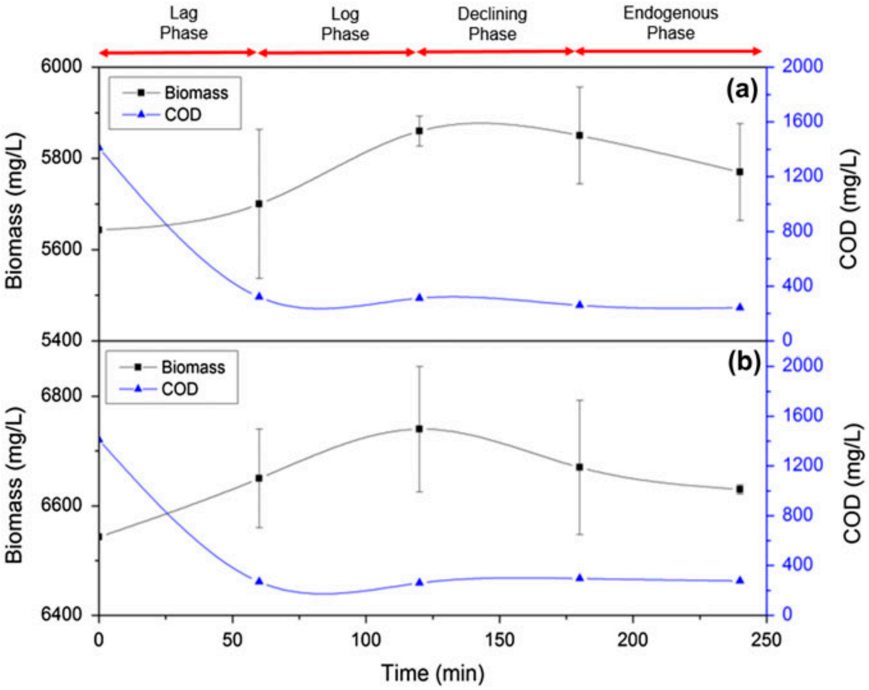

Fig. 2. Biomass growth and COD removal at batch 2 of acclimatization phase for SBR (a) and EM-SBR (b).

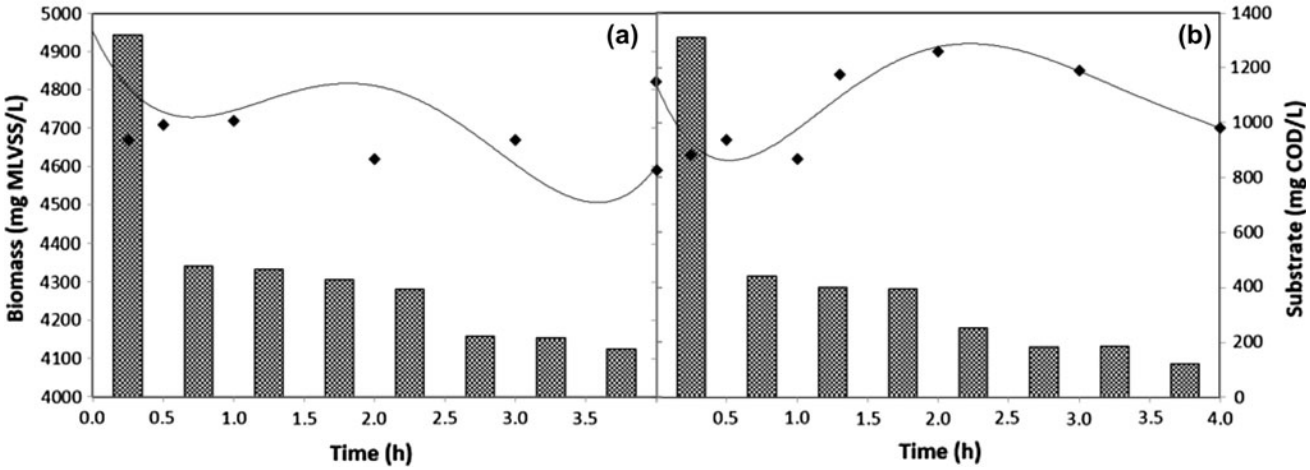

Fig. 4. Biomass growth performance and COD biodegradation at the volumetric loading ratio of 1.0 for SBR (a) and EM-SBR (b).

loading for the biomass to degrade is also increased. Thus, more microbial biomass is required to degrade higher amount of organic matter. Simultaneous with the removal of COD, the microbial cell also propagated exponentially due to the excess amount of organic matter. Explosive growth of microbial cell leads to the starvation condition and the death of the degrading micro-organism. The cell of micro-organism released the absorbed substrate back to the surrounding water thus lead to the lower substrate removal at high volumetric loading of 1.5 and higher (Fig. 3). COD removal efficiency increased with the increasing of volumetric loading ratio and decrease as it exceed the ratio of 1.5. The highest COD removal efficiency of 80% was achieved at the ratio of 1.0 for both SBR and EM-SBR. This results was compatible than that obtained by Fongsatitkul et al. (average 85%) who used a similar treatment at stage 1 [18]. Further increment of volumetric loading ratio did not contribute to the increase of COD removal mainly because of stress condition resulting from high loading of toxic organic matter into the wastewater. High concentration of organic matter leads to the physiological stress on the bacterial cell thus interrupting its growth and remediation performance [24].

At the volumetric loading ratio of 1.0, COD removal occurs mostly during the lag phase as the microbial cell in the activated sludge the readily available organic substrate for cell maintenance prior to the exponential growth in the log phase (Fig. 4). This explained the lower COD removal in the log phase as compared to the lag growth phase. In addition, the growth performance of biomass and COD removal of EM-SBR were significantly higher as compared to SBR without the inoculation of EM. Inoculation of EM in the activated sludge introduced beneficial bacteria in regulating the wastewater condition thus supporting better microbial adaptation.

4. Conclusion

The five-step SBR approach for COD removal from wool processing wastewater was adopted in this study. The results proved that SBR was able to degrade COD concentration in the wastewater effluent of wool processing industry. The step-by-step feeding approach successfully achieved the COD removal of more than 80% for all batches at various volumetric loading ratios. In this study, the optimum volumetric loading ratio was determined at 1.0. Inoculation of EM in the activated sludge also significantly improved the COD removal efficiency of the treatment system.

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References

[1] J.-J. Long, C.-L. Cui, L. Wang, H.-M. Xu, Z.-J. Yu, X.-P. Bi, Effect of treatment pressure on wool fiber in supercritical carbon dioxide fluid, J. Cleaner Prod. 43 (2013) 52–58.

[2] M. Niu, X. Liu, J. Dai, W. Hou, L. Wei, B. Xu, Molecular structure and properties of wool fiber surface-grafted with nano-antibacterial materials, Spectrochim. Acta, Part A 86 (2012) 289–293.

[3] W. Xu, G. Ke, J. Wu, X. Wang, Modification of wool fiber using steam explosion, Eur. Polym. J. 42(9) (2006) 2168–2173.

[4] M.J. Savage, Intergrated Treatment Process for Primary Wool Scouring Effluent, University of Canterbury, Christchurch, 2002.

[5] D.I.a.R. Cord-Ruwish, Anaerobic degradability of wool scouring effluent, International Conference on “Appropriate Waste Management Technologies, Perth, Western Australia, 1991, pp. 125–128.

[6] A.J. Poole, R. Cord-Ruwisch, Treatment of strongflow wool scouring effluent by biological emulsion destabilisation, Water Res. 38(6) (2004) 1419–1426.

[7] J. Labanda, J. Llorens, Wool scouring waste treatment by a combination of coagulation–flocculation process and membrane separation technology, Chem. Eng. Process. Process Intensif. 47(7) (2008) 1061–1068.

[8] H.M. Ang, F. Himawan, Treatment of wool scouring wastewater for grease removal, J. Hazard. Mater. 37(1) (1994) 117–126.

[9] Z. Laijiu, D. Bing, H. Zeshou, Treatment of wool scouring wastewater by immobilized chitosan biomembrane, J. Eng. Fibers Fabr. 8(1) (2013) 1–5.

[10] A.J. Poole, Treatment of biorefractory organic compounds in wool scour effluent by hydroxyl radical oxidation, Water Res. 38(14) (2004) 3458–3464.

[11] J.I. Kim, S.K. David, The photostability of shrinkproofing polymer systems on wool fabric, Polym. Degrad. Stab. 38(2) (1992) 131–137.

[12] D. Petry, Wool Without Compromises: Enzymes Stop Felting of Wool, Textile Auxiliaries, Reutlingen, 2008.

[13] M.L. Leong, K.M. Lee, S.O. Lai, B.S. Ooi, Sludge characteristics and performances of the sequencing batch reactor at different influent phenol concentrations, Desalination. 270(1) (2011) 181–187.

[14] S. Sirianuntapiboon, K. Chairattanawan, M. Rarunroeng, Biological removal of cyanide compounds from electroplating wastewater (EPWW) by sequencing batch reactor (SBR) system, J. Hazard. Mater. 154(1) (2008) 526–534.

[15] F. El-Gohary, A. Tawfik, Decolorization and COD reduction of disperse and reactive dyes wastewater using chemical-coagulation followed by sequential batch reactor (SBR) process, Desalination 249(3) (2009) 1159–1164.

[16] S.A. Ong, P.E. Lim, C.E. Seng, Effects of adsorbents and copper(II) on activated sludge microorganisms and sequencing batch reactor treatment process, J. Hazard. Mater. 103(3) (2003) 263–277.

[17] S.V. Mohan, N.C. Rao, K.K. Prasad, B.T.V. Madhavi, P.N. Sharma, Treatment of complex chemical wastewater in a sequencing batch reactor (SBR) with an aerobic suspended growth configuration, Process Biochem. 40(5) (2005) 1501–1508.

[18] P. Fongsatitkul, P. Elefsiniotis, A. Yamasmit, N. Yamasmit, Use of sequencing batch reactors and Fenton’s reagent to treat a wastewater from a textile industry, Biochem. Eng. J. 21(3) (2004) 213–220.

[19] F.J. Fernández-Morales, J. Villaseñor, D. Infantes, Modeling and monitoring of the acclimatization of conventional activated sludge to a biohydrogen producing culture by biokinetic control, Int. J. Hydrogen Energy 35(20) (2010) 10927–10933.

[20] APHA, Standard Methods for the Examination of Water and Wastewater, twenty-first ed., American Public Health Association, Washington, DC, 2005.

[21] Y. Liu, Q.-S. Liu, Causes and control of filamentous growth in aerobic granular sludge sequencing batch reactors, Biotechnol. Adv. 24(1) (2006) 115–127.

[22] T. George, L. Franklin, H.D. Stensel, Wastewater Engineering: Treatment and Reuse, Metcalf & Eddy, Inc., New York, NY, 2003.

[23] W.H.W. Osman, S.R.S. Abdullah, A.B. Mohamad, A.A.H. Kadhum, R.A. Rahman, Simultaneous removal of AOX and COD from real recycled paper wastewater using GAC-SBBR, J. Environ. Manage. 121 (2013) 80–86.

[24] C.M. Bergamo, R. Di Monaco, S.M. Ratusznei, J.A.D. Rodrigues, M. Zaiat, E. Foresti, Effects of temperature at different organic loading levels on the performance of a fluidized-bed anaerobic sequencing batch bioreactor, Chem. Eng. Process. Process Intensif. 48(3) (2009) 789–796.