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Pretreatment of silk-dyeing industrial wastewater by UASB reactor

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Abstract The objective of this study was to investigate the performance of the upflow anaerobic sludge blanket (UASB) reactor as the pretreatment system for silk-dyeing wastewater. Two laboratory-scale UASB reactors, with working volume of 15.59 l, were used during May 1998 to June 1999. The actual wastewater was diluted to reduce ammonium ion toxicity on anaerobic bacteria. The experiments were conducted at the organic loading rates (OLRs) of 0.52, 1.01, 1.04, 1.54 and 2.56 kgCOD/(m^3.d), treating only wastewater generated from the acid-dye process of mixed-species raw silk. It took approximately 4½ months to reach the steady-state conditions. It was found that the COD removal was in the ranges of 74.1–85.3% , except at OLR 2.56 kgCOD/(m^3.d) where efficiency significantly dropped to 55.2%. The apparent color removal was in the similar trend as COD. During the study periods, wastewater input had various color shades while the effluent generally looked pale yellowish. The methane generation rates ranged from 0.18–0.31 m^3/kg COD removed, with methane composition 81.0–88.1% in biogas. The average granule size in the sludge bed had slowly increased to 0.73 mm in the last experiment. It can be concluded that the UASB reactor is suitable as a pretreatment system for silk-dyeing wastewater. An OLR of 1 kgCOD/(m^3.d) and an influent concentration diluted to 2,600 mgCOD/l are suggested while COD and apparent color removal efficiency of 80% and 70%, respectively, can be expected.

Keywords Apparent color; biogas; COD; silk-dyeing wastewater; true color; UASB

Introduction

Silk-dyeing in Thailand is processed in both industrial-scale and household factories. The household level production is mainly located in the north and northeastern regions, employing traditional and less mechanized procedures. According to Thailand's Ministry of Industry, the household industry can operate without registration and is not required to treat the wastewater. These small dyeing entrepreneurs generally operate in batch processes and directly discharge their wastewater without treatment. Since silk-dyeing wastewater contains high organic matter and color, conflicts with nearby residents are common, especially due to color in receiving water bodies. It is therefore essential that a simple treatment process be developed to treat the wastewater. The anaerobic process was found to be feasible in terms of color removal as well as organic matter reduction (Setiadi and Van Loosdrecht, 1997). The objective of this study was therefore to investigate the performance of a UASB reactor as a pretreatment system for silk-dyeing wastewater, generated from household industry.

Material and methods

Two laboratory-scale UASB reactors (Figure 1), made from transparent acrylic tubes with the dimensions of 63 mm × 5 m (diameter × height) and 15.59 l total working volume, were used. The gas-solids separator was installed at 4.25 m height. The wastewater was collected monthly from Pensiri Thai Silk Co. Ltd., Lamphoon province, which was 35 km from Chiang Mai University. It was stored in a 4°C room prior to using. The reactors were seeded

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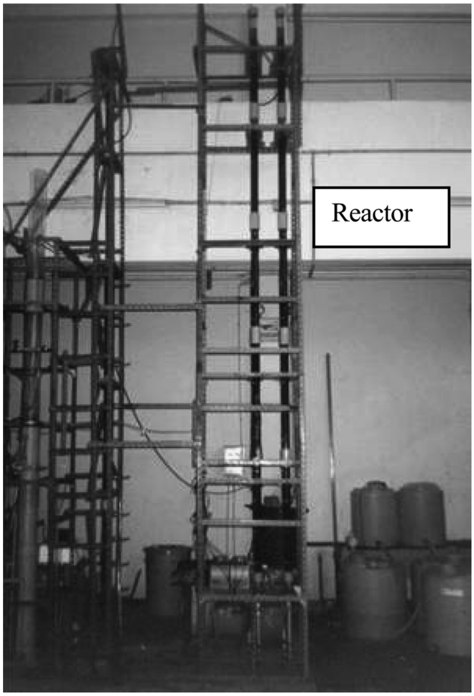

Figure 1 Experimental units

with anaerobically digested sludge at the concentration of 2,200 mgVSS/l. The experimental conditions are presented in Table 1. The wastewater was collected during the acid-dye process of mixed-species raw silk in runs 1 and 2. In run 3, different types of wastewater (i.e. from many species of raw silk) were treated. The input wastewater was continuously pumped to the bottom of the reactors by a peristaltic pump: Gilson – model Miniplus 3. There was no effluent recycling during this study.

The biogas volume was measured daily by a water replacement tank. The composite water samples were collected at the inlet and outlet storage tanks. They were generally analyzed according to Standard Methods (1995), except volatile fatty acids which followed Dillalo and Albertson (1960). The space unit procedure was adopted for color measurement, i.e. total area under absorbance of 400–700 nm. The experiments were conducted at the Department of Environmental Engineering, Chiang Mai University, Thailand, during May 1998 to June 1999.

Results and discussion

Pensiri Thai Silk Co. Ltd. is a typical household silk-dyeing factory in northern Thailand. The production is batch-operated with average wastewater volume of 0.3 m^3/d and finished product of 80 kg silk/d. Each day, different types and color shades of dyes are used. The

Table 1 Experimental conditions

Run number	Reactor	Organic loading rates, kgCOD/(m^3.d)	Inflow, l/d	Hydraulic retention time, h	Upflow liquid velocity, m/h
1	A	1.54	9.4	39.8	0.12
	B	2.56	15.6	24.0	0.21
2	A	0.52	3.1	120.0	0.04
	B	1.04	6.2	60.0	0.08
3	B	1.01	6.2	60.0	0.08

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wastewater has very high color shade variations as well as other characteristics. The raw silk contains about 25% of silk-glue (sericin) which is a natural protein. During the scouring process with alkali and soap, sericin is washed out, resulting in total Kjeldahl nitrogen (TKN) concentration as high as 700 mg/l. There are three types of dyes used in this factory, i.e. acid (about 70% of total operation), reactive and direct dyes. Only wastewater generated from the acid-dyeing process was treated in this study. After UASB seeding for 3 weeks and sufficient biogas occurred, the wastewater was gradually fed to the UASB reactors. During the initial period, wastewater was directly fed to the UASB reactors and ammonium ion toxicity caused the system to fail. The biogas gradually decreased to zero within 13 days. To reduce this effect, the raw wastewater was diluted to maintain the stable concentration at the ratios of wastewater: tap water at 1:2–1:10. The diluted wastewater characteristics are presented in Table 2.

After wastewater dilution, the efficiency slowly improved and the inflow was stepwise increased until organic loading rates (OLRs) reached 1.54 and 2.56 kgCOD/(m^3.d) in reactors A and B, respectively. The steady state conditions were reached at 132 and 141 days after start up, respectively, having effluent FCOD variations within 15%. The FCOD variations during start up are shown in Figure 2.

It was found that the UASB system took a relatively long time to reach the steady state condition during the start up period. This may be due to the quality of seeded sludge as well as wastewater characteristics, which contain color pigments that are not easily biodegradable. During the first 2 months, the effluent FCOD concentrations significantly fluctuated along with the influent values and steadily became stable afterwards. There was sufficient alkalinity in the influent and the high ammonium ion, generated from organic matter oxidation, helped stabilizing the pH by forming ammonium bicarbonate. There was no pH adjustment throughout the study. The effluent total alkalinity was higher than the influent. During run 1, six color shades of wastewater were treated. It was found that the influent apparent and true color units were significantly different among color shades. No relationship between shade of color and space unit was found. The true color space unit, measured

Table 2 Characteristics of influent wastewater

Parameter	Range
COD, mg/l	2,500–2,700
Filtered COD, mg/l	1,800–2,000
BOD_5, mg/l	1,200–1,050
pH	7.8–8.0
Suspended solids, mg/l	230–300
Volatile suspended solids, mg/l	200–230
Total alkalinity, mg/l as $CaCO_3$	550–760
Volatile fatty acids, mg/l as acetic acid	400–700
TKN, mg/l	250–300
Total phosphorus, mg/l	5.0–5.1

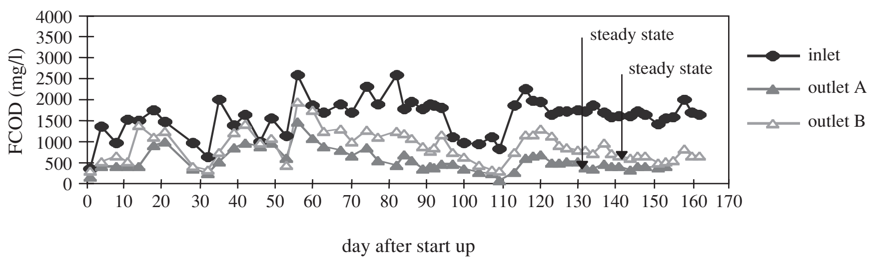

Figure 2 FCOD variations during start up

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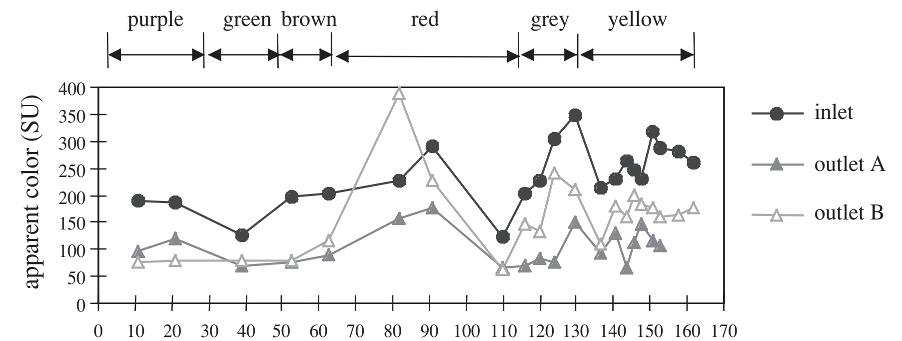
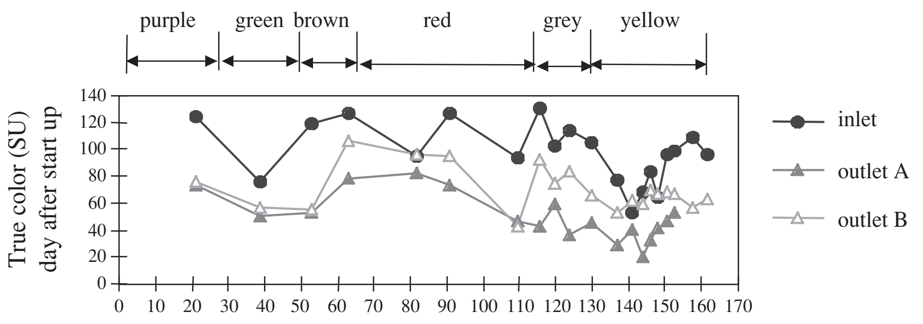
after centrifuging at 1,500 rpm for 40 min, was approximately half of the apparent color indicating color pigment adsorption in suspended solids. Although the influent contained different color shades, the effluent generally looked pale yellowish as natural water. The color variations in run 1 are shown in Figure 3.

During run 2, OLRs were reduced and the reactors reached steady state conditions within 50 days. In run 3, reactor B treated wastewater with a total of 14 color shades. Although the influent color had extreme variations, the UASB reactor could distinctly stabilize the color, having the effluent being pale yellowish. However, the system could not effectively remove black color. Although the color space unit was reduced the black color shade appeared in the effluent. According to Thailand's Ministry of Industry (1996), the effluent standard for color is subjective and specified as "not objectionable". Although the space unit procedure is good for relative comparison, the color unit has no relationship with the shade of color or objection opinion by the public. However, the color of the UASB effluent is more likely to be acceptable than raw wastewater. The overall system performance at steady state conditions is presented in Table 3. The relationship between OLRs and COD/apparent color removal is shown in Figure 4.

It was found that the COD removal was in the ranges of 74.1–85.3% , except at OLR 2.56 kgCOD/(m^3.d) where efficiency significantly dropped to 55.2%. The apparent color was removed in the similar trend, ranging from 49.7–70.8%, except at OLR 2.56 kgCOD/(m^3.d) where efficiency was 32.6%. According to Figure 4, the OLR of 1 kgCOD/ (m^3.d) is suggested as a suitable design criterion. The COD and apparent color removal of 80% and 70%, respectively, can be expected. This treatment level is sufficient as a pretreatment step. A post treatment is also required for further reduction of organic matter and color.



a) apparent color



b) true color

Figure 3 Color variations during start up

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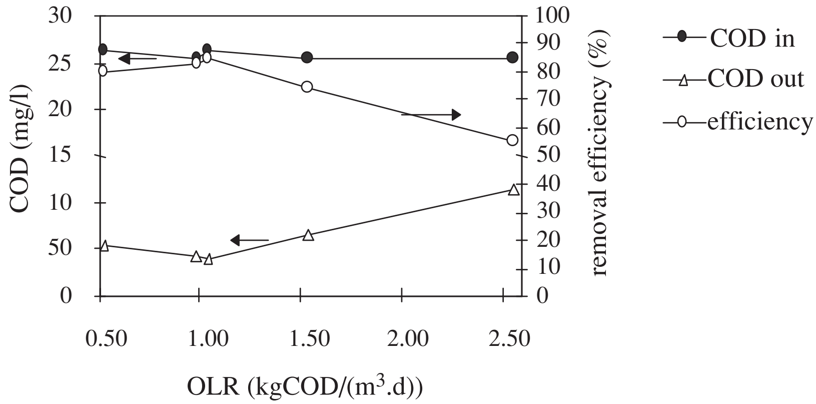
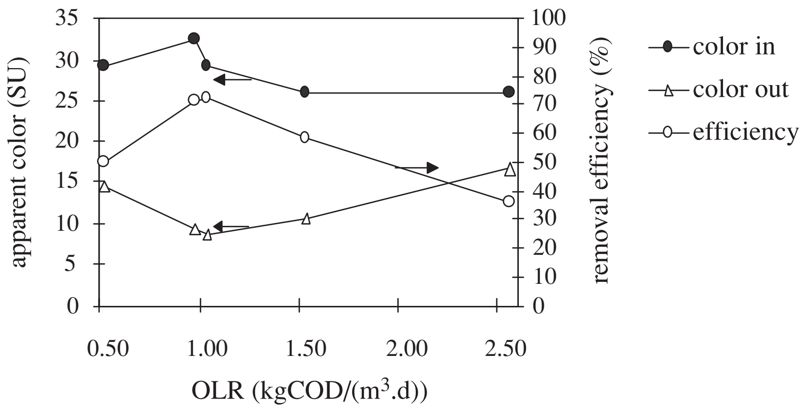
Table 3 Overall UASB reactor performances

Parameter	Organic loading rate, kgCOD/(m^3.d)									
	0.52		1.01		1.04		1.54		2.56	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
COD, mg/l	2,621.6	527.9	2,545.6	426.5	2,621.6	386.1	2,560.6	662.2	2,560.6	662.2
FCOD, mg/l	1,571.2	264.5	1,614.7	273.3	1,571.2	241.0	1,666.0	405.2	1,666.0	637.9
Apparent color, space	290.1	146.0	323.8	97.6	290.1	84.8	257.2	107.7	257.2	173.4
unit	290.1	146.0	323.8	97.6	290.1	84.8	257.2	107.7	257.2	173.4
True color, space unit	126.9	64.6	154.4	41.6	126.9	35.0	82.1	37.0	82.1	63.5
Suspended solids, mg/l	410.8	248.2	409.1	173.0	410.8	132.9	327.9	181.6	327.9	254.1
Volatile suspended solids, mg/l	369.2	225.3	363.1	160.4	369.2	118.5	288.1	165.7	288.1	231.6
Total alkalinity, mg/l $CaCO_3$	837.6	996.4	1006.9	1383.3	837.6	1040.4	712.9	1131.3	712.9	1095.0
Volatile fatty acids, mg/l acetic acid	636.6	335.0	649.4	408.5	636.3	336.7	633.1	328.6	633.1	426.3
pH	7.69	6.92	7.87	6.86	7.69	6.95	7.55	6.92	7.55	6.93



a) COD



b) apparent color

Figure 4 Relationship between organic loading rate and COD/apparent color removal

During the study, the sludge beds with high volatile suspended solids concentrations were formed at the bottom of the reactors. The vertical profile concentrations are shown in Figure 5.

The average sludge bed height and VSS concentrations in all runs were found to range over 0.4–0.9 m and 9,500–24,000 mg/l, respectively. The sludge bed was responsible for

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most of organic matter and color removal, as shown in Figure 5. The rate of reaction in the flocculent sludge blanket (VSS ~ 2,500 mg/l) in the upper part of the reactor was relatively reduced. It was found that the apparent color units along reactor height were significantly higher than the effluent, indicating the color adsorption is by the sludge blanket. The granulation of UASB sludge, sampling at 0.15 m from bottom, was observed via microscope. It was found that the granule size (Figure 6) gradually increased with operating times as presented in Table 4.

The relationship between OLRs and methane production rates and methane proportion in biogas are shown in Figure 7. The biogas was found to contain a high proportion of methane (81.0–88.1%). It is expected that a large portion of carbon dioxide generated in the reactor had reacted with ammonium ion resulting in a relatively low proportion in the biogas. The methane production rates, calculated at standard conditions, were found to be 0.18–0.31 m^3/kgCOD removed. The rates had a decreasing trend with increasing OLRs.

The acidification and methanogenization in the UASB reactor were calculated based on COD mass balance. The relationship with OLRs is presented in Figure 8.

It was found that acidification and methanogenization efficiency followed the similar trend as the methane production rate. At higher OLRs, the efficiency significantly dropped indicating system limitation.

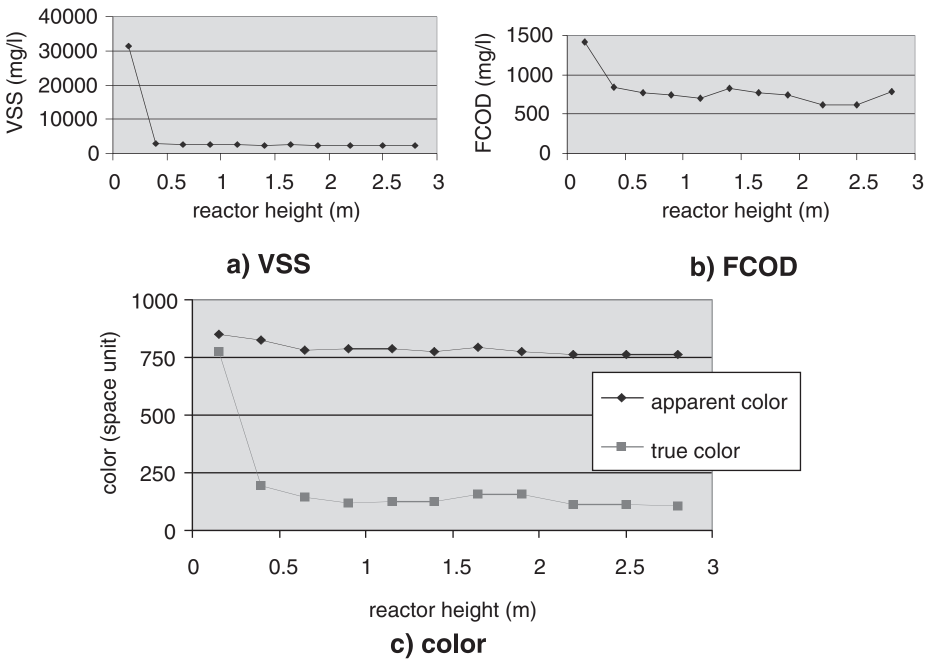

Figure 5 Vertical profile concentrations of reactor B in run 2

Table 4 Size of granular sludge

Run number/reactor	OLR, kgCOD/(m^3.d)	Day after start up	Diameter, mm	
			Range	Average
1/A	1.54	162	0.18–0.67	0.40
1/B	2.56	162	0.15–0.55	0.29
2/A	0.52	225	0.21–0.71	0.56
2/B	1.04	225	0.22–0.75	0.52
3/B	0.98	285	0.29–1.20	0.73

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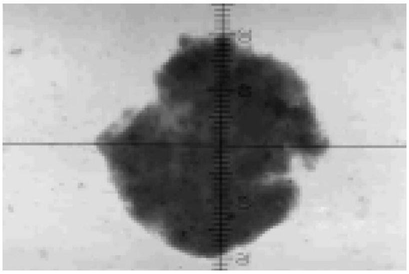
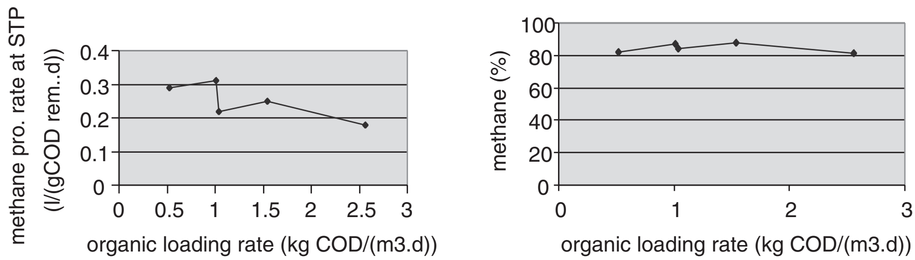


Figure 6 Granular sludge at 285 days after start up



a) production rate at STP **b) proportion**

Figure 7 Relationship between organic loading rate and methane production/proportion in biogas

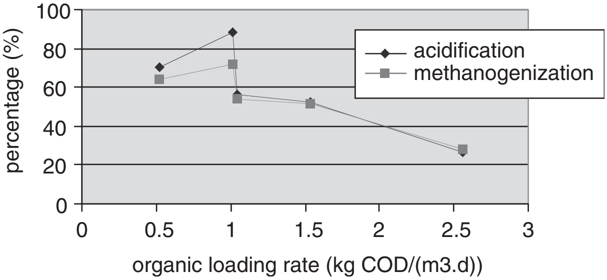


Figure 8 Relationship between organic loading rate and acidification/methanogenization

The UASB system was experimentally confirmed to be quite effective as a pretreatment step for silk-dyeing wastewater. Besides the long start up period, the operation is simple and requires little energy input. Due to the small size of household factories, the cost of dilution water, i.e. 1–3 m^3/d, is considered as affordable. A simple post treatment system such as facultative pond or constructed wetland, etc., is also required. The installation of a wastewater treatment plant in a household factory can help alleviate the social conflict among nearby villagers and entrepreneurs. The harmonization of environmental and economic development can therefore be achieved.

Conclusions

Based on the results obtained, the following conclusions can be drawn. First, the silk-dyeing wastewater can be pretreated by the UASB reactor provided that the wastewater be diluted to 2,600 mgCOD/l to reduce ammonium toxicity. Second, the OLR of 1 kgCOD/(m^3.d) is suggested as a suitable design criterion. The COD and apparent color removal efficiency of 80% and 70%, respectively, can be expected. Third, the system can successfully remove various color shades except black color. The effluent generally looks pale yellowish.

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