Onsite Wastewater Treatment of Household Industry (Saa Paper Pulping) by Hybrid Subsurface Flow Constructed Wetland System

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Abstract

The pilot-scale hybrid subsurface flow constructed wetland system, i.e. vertical subsurface flow constructed wetland (VSF) and horizontal subsurface flow constructed wetland (HSF), was used to treat Saa paper pulping wastewater. Three VSFs, each with surface areas of 0.78 m^2, were operated at the hydraulic loading rates (HLRs) of 1.3 - 67.0 cm/d. The treatment efficiency of VSF was relatively low and it was only suitable as pretreatment step. The effluent of one VSF was further treated by HSF, having surface areas of 3 m^2. The hybrid system was operated for 3 runs at HLRs of VSF/HSF at 5.0/1.3, 13.4/3.4 and 67.0/59.7 cm/d, respectively. The hybrid system's performances were better, especially in terms of color removal. Due to various constraints, partial treatment by hybrid system targeting at BOD and color removal of 76 % and 55 %, respectively, is suggested.

Keywords: Color, HLR, HSF, Saa Paper, VSF

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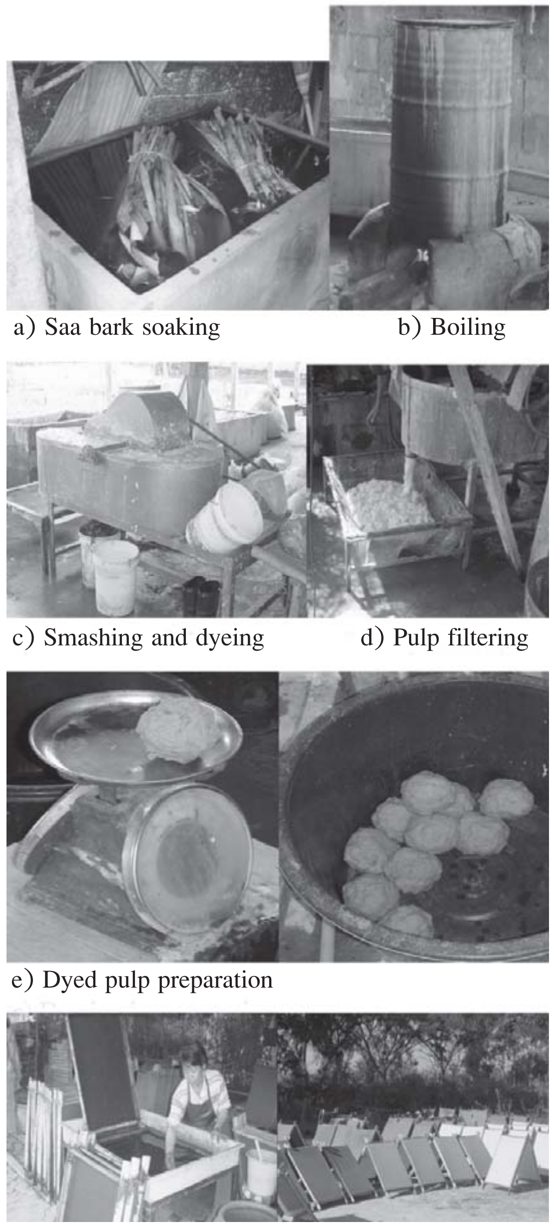
Introduction

Saa paper is a traditional product in northern and northeastern Thailand and classified as one of the OTOP (one tambon one product) of the north. It is made from bark of mulberry (or Saa in Thai) trees and can be fabricated into various products such as greeting cards, book covers, lanterns, boxes, etc. A lot of Saa paper is produced by household industry. According to Thailand industrial regulation, household producer is not required to register or treat wastewater and direct discharge of wastewater is common. The water pollution problems from small scale producers are therefore obvious in many areas, especially in Tonpao village, Amphoe Sankhampaeng, Chiang Mai province which is the center of household Saa paper industry. This village is in Tonpao municipality which has no central domestic wastewater treatment plant. The area is provided with combined sewers which discharge untreated wastewater to the nearby small canals. Since Saa paper producer has limited budgets and manpower, the appropriate onsite treatment system which is easy to operate and has low operation and maintenance costs is needed. The objective of this study was to develop the prototype treatment plant, using hybrid subsurface flow constructed wetland system. The wastewater from Saa pulping process was treated onsite at various HLRs to determine the suitable design criteria.

For paper production, wastewater is discharged at the end of the day in small quantity and thus considered as insignificant. Another group of entrepreneurs makes final products by purchasing plain papers from other producers. Both finished products and plain papers are partially exported. According to Thailand industrial regulation, household producer is not required to register or treat wastewater and direct discharge of wastewater is common. The water pollution problems from small scale producers are therefore obvious in many areas, especially in Tonpao village, Amphoe Sankhampaeng, Chiang Mai province which is the center of household Saa paper industry. This village is in Tonpao municipality which has no central domestic wastewater treatment plant. The drainage area is provided with combined sewers which discharge untreated wastewater to the nearby small canals. To avoid conflicts, some producers move the pulp production lines to remote villages and send



a) Saa bark soaking b) Boiling
c) Smashing and dyeing d) Pulp filtering
e) Dyed pulp preparation
f) Pulp mixing on bath g) Sun drying

Figure 1. Saa paper production

dyed pulp for paper production at home. Since Saa paper producer has limited budgets and manpower, the appropriate onsite treatment system which is easy to operate and has low operation and maintenance costs is needed. The objective of this study was to develop the prototype treatment plant, using hybrid subsurface flow constructed wetland system. The wastewater from Saa pulping process was treated onsite at various HLRs to determine the suitable design criterion.

Material and Methods

The pilot-scale experimental units were constructed in the compound of Mrs. Supat Kattikhun, a pulp producer in Tonpao village. She produced pulp using average Saa bark of 50 kg/d. The wastewater was originally pumped out to the nearby open land without treatment. The experiments were divided into 2 parts. The first part emphasized on treatment efficiency of VSF. Three VSFs, made from concrete rings with diameter 1.0 m, surface areas of 0.78 m^2, height 0.8 m and filled with 0.7 m rock, were used. The VSF media included 0.6 m layer of crushed limestone (diameter 20 -25 mm) and 0.1 m layer (diameter 5-10 mm) at the surface. The second part of study was the hybrid subsurface flow constructed wetland system, as shown in Figure 2. The effluent of one VSF was further treated by HSF. The HSF system, made from reinforced concrete with the dimension of 1.0 m width, 3.0 m length, surface areas of 3 m^2, 1.0 m height and filled with 0.8 m rock, was used. The HSF media included 0.7 m layer of crushed limestone (diameter 20-25 mm) and 0.1 m layer (diameter 5-10 mm) at the surface. All units were planted with umbrella-sedges (*Cyperus spp.*) at 0.25 x 0.25 m spacing. The wastewater from existing pump sump was partially pumped to the distribution box equipped with 3 rectangular weirs for inflow control to VSFs. The pumping period was set intermittently by timer, i.e. start 4 min and stop 56 min, during 9 AM – 4 PM which was average working time. There were totally 3 runs in this study. In the 3rd run, all waste-water from the production line was treated by the hybrid system. The experimental conditions are presented in Table 1.

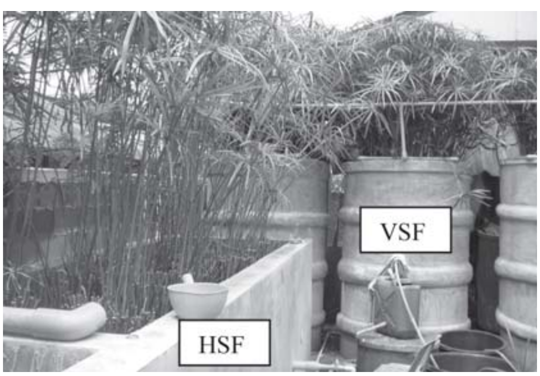


Figure 2. Photograph of the hybrid system

Table 1. Experimental conditions

Run	Inflow (l/d)	HLR (cm/d)			Study period (d)
		VSF	Hybrid System		
			VSF	HSF	
1	43.3	5.5	-	-	130
	105.5	13.4	13.4	3.4	
	197.7	25.2	-	-	
2	10.0	1.3	-	-	127
	19.7	2.5	-	-	
	39.7	5.0	5.0	1.3	
3	1,790	67.0	67.0	59.7	49

The grab samples of influent and effluent of all units were weekly taken as well as two additional sampling points in HSF, i.e. 1-m and 2-m from the inlet. The water samples were analyzed at the Environmental Science Laboratory of Chiang Mai Rajabhat University according to "Standard Methods" (APHA, 1998). The space unit (SU) procedure was adopted for color measurement, i.e. total area under absorbance of 400-700 nm.The experiments had been conducted under tropical climate for 13 months during April 2006 -April 2007.

Results and Discussion

Since the production system is very small, high fluctuations in wastewater characteristics were observed. The wastewater concentrations in run 2 were relatively higher than other runs. There were high dissolved ions with average conductivity and total solids in 3 runs at 1,686 - 2,658 micro mho/cm and 3,669 - 4,308 mg/l, respectively. The average total Kjeldahl nitrogen and total phosphorus were 23.1 - 46.2 and 41.1 - 55.9 mg/l. The ratios of BOD: N were slightly high at 100:2.7 - 100:4.2. According to Metcalf & Eddy, Inc. (2004) the minimum BOD: N ratio is 100:5 to ensure sufficient nutrients for bacterial cell growth and these high ratios indicated nitrogen deficiency. The average filtered COD (FCOD) : COD ratios in wastewater were 0.63 and 0.83 in run 1 and 2, respectively. The BOD: COD ratios were extremely low, i.e. 0.28 - 0.35, indicating the low proportion of biodegradable organic matter in wastewater. It is hypothesized that lignin released during boiling process contributed to the high proportion of non-biodegradable organics. The average influent temperatures were 27.3- 27.5 °C and the effluent temperatures slightly decreased. The average values of color in 3 runs were 395 - 455 SU. Although NaOH was used in bark boiling process, the subsequent washing water diluted the alkali so that the influent pH values were in neutral range, 7.1-7.7. The effluent pH values did not much differ from the influent and there was no pH adjustment throughout the study. The VSF system's performances are summarized in Table 2.

Table 2. VSF system's performances

HLR (cm/d)	Color			SS		
	Inf. (SU)	Eff. (SU)	Rem. (%)	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)
1.3		208	50.2		517	44.0
2.5	419	224	46.5	923	508	45.0
5.0		273	34.8		569	38.3
5.5		241	47.0		667	48.7
13.4	455	322	29.4	1,299	823	36.6
25.2		391	14.1		979	24.6
76.0	395	326	17.4	1,206	838	30.5

HLR (cm/d)	COD			FCOD			BOD		
	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)
1.3		1,213	50.3		915	41.1		247	71.1
2.5	2,442	1,255	48.6	1,553	945	39.2	855	390	54.4
5.0		1,346	44.9		997	35.8		485	43.3
5.5		2,078	47.2		1,706	48.1		260	76.3
13.4	3,939	2,270	42.4	3,286	1,880	42.8	1,096	389	64.5
25.2		2,400	39.1		2,010	38.8		458	58.2
76.0	2,534	1,995	21.9	1,935	1,597	17.5	885	649	26.7

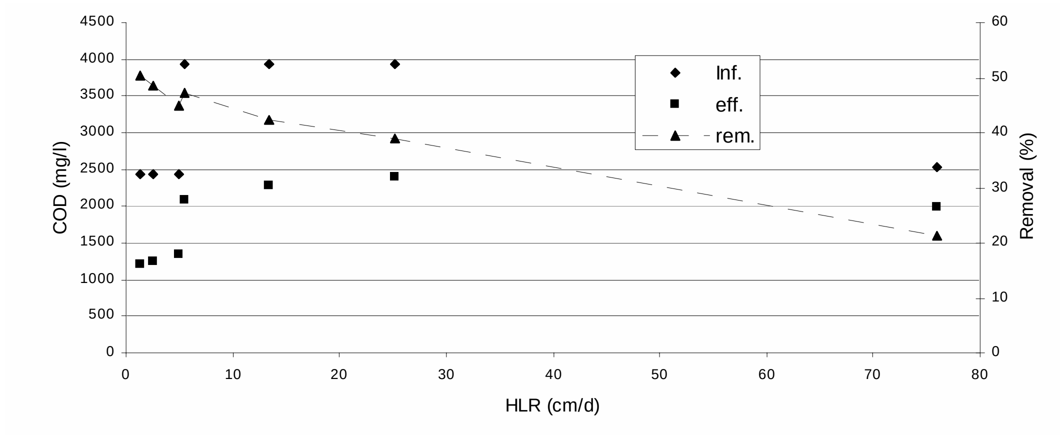
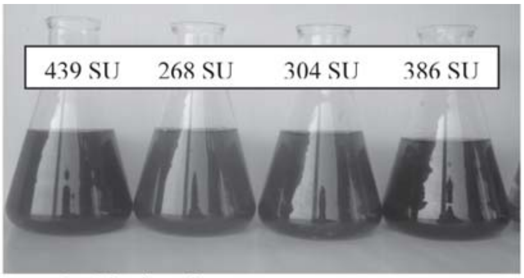


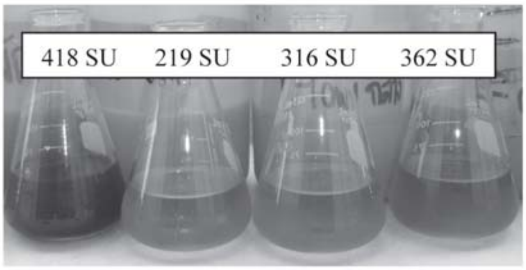
Figure 3. Relationship between HLR and COD removal

The effluent normally flowed for 5-10 min during the 4-min feeding time. The treatment efficiency of VSF system generally decreased with increasing HLRs. However, higher influent concentration resulted in higher efficiency as observed in run 2. The typical operations of VSF include intermittent feeding with rest period which allows oxygen penetration into media bed to promote aerobic condition (Cooper et al., 1996). The removal mechanisms in constructed wetland are complex, including aerobic reaction near root zone, anoxic and anaerobic reaction at farther distance as well as physical operations (sedimentation, adsorption). The sedimentation of suspended organics within the media's pores is another major mechanism. The COD removal was found to be rather low, in the range of 21.9 - 50.3%, and had decreasing trend with increasing HLRs as shown in Figure 3. The highest efficiency was found at HLR 1.3 cm/d. The FCOD removal in run 2 (low influent FCOD) was lower than COD removal. In run 1 (high influent FCOD) the FCOD removal was generally close to COD removal. The BOD removal was higher than COD removal as generally found in biological treatment processes since the biodegradable organics, reported as BOD, could be more easily oxidized. The VSF could remove BOD ranging from 26.7 – 76.3%, with highest value at HLR 5.5 cm/d. The effluent of VSFs had lower BOD:COD ratio than the inlet and consisted of higher proportion of nonbiodegradable organics.

The HLRs employed were relatively high as compared to the ranges 1.4 – 4.6 cm/d, suggested for subsurface flow constructed wetland (U.S. EPA,1988). The surface organic loading rates were 111- 5,929 kg BOD/(ha-d) which also exceeded the maximum suggested value of 67 kg BOD/(ha-d) (U.S. EPA,1988).The high organic loading rates may lead to oxygen- limited condition and poor organic matter removal. The SS removal followed the same trend as COD with relatively low efficiencies, i.e. 24.6 – 48.7%. For color removal, it was difficult to assess the efficiency since there was no relationship between shade of color and SU, similarly to silk- dyeing wastewater (Karnchanawong and Sawangpanyangkura, 2004). Two wastewaters with the same SU may have different appearance due to shade of dyes, as shown in Figure 4.



a) Lignin color

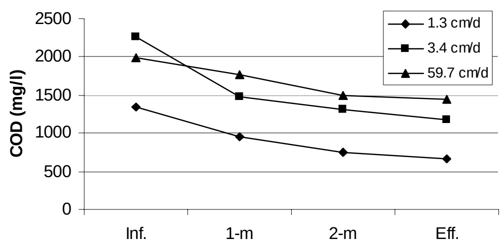


b) Dyeing color of blue

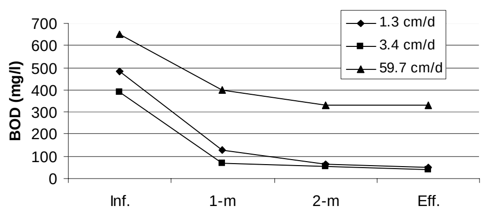
Figure 4. Photograph of wastewater color during run 2

The dark brown color in Figure. 4 (a) is due to the formation of lignin degradation products during the processing of lignocelluloses from paper and pulp manufacture (Singh and Thakur, 2006). The dyeing wastewater had various colors which dominated the color of mixed wastewater. At low HLRs, the dye pigments can be degraded faster than lignin and the final effluent color was usually pale brown. The SU is used to compare the color removal and lower HLR generally resulted in lower SU. The color removal mechanism was due to bond breaking of color pigment in anaerobic process, as found in textile wastewater (Setiadi and Loosdrocht, 1997). Since VSF had relatively more aerobic environment, the color pigments were sometimes not much degraded, as shown in Figure. 4 (b). It was found that HLR 13.4 cm/d or higher gave little color removal. According to this study, VSF operated at the lowest HLR (1.3 cm/d) could not treat Saa pulping wastewater to the acceptable quality. The VSF is therefore considered as pretreatment for HSF.

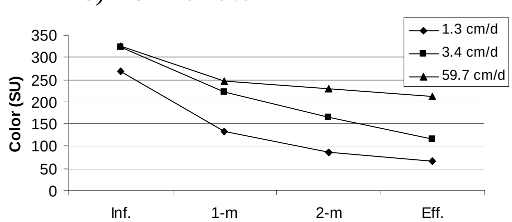
In HSF, the water level was controlled at 0.1 m below media surface and the operating condition was more anoxic/anaerobic than VSF. The color removal was therefore enhanced in HSF. The longitudinal profile of COD, BOD and color at various HLRs are shown in Figure. 5.



a) COD removal



b) BOD removal



c)Color removal

Figure 5. Longitudinal profile of COD, BOD and color in HSF

The COD and BOD were significantly removed in the first 1- m length of HSF. During the 1 to 3 m length, the BOD removal was little while COD and color removal still continued throughout the reactor's length. At low HLRs, 1.3 and 3.4 cm/d, color removal was sufficiently higher than at high HLR, 59.7 cm/d. However, HSF was very superior in terms of color removal and dye pigments were completely degraded so that effluent always looked pale brown from lignin. The HSF system's performances are summarized in Table 3. The comparison of HSF performeances was rather difficult since the influent concentrations were different. At HLR 1.3 and 3.4 cm/d, the BOD and color removal was sufficiently high. The neighbor's opinions who visited the site were positive although the water quality did not compile with Thailand industrial effluent standard (Ministry of Industry, 1996).

Table 3. HSF system's performances

Parameter	HLR (cm/d)			Std.[1] (mg/l)
	1.3	3.4	59.7	
COD				120
- Inf. (mg/l)	1,346	2,270	1,995	
- Eff.(mg/l)	662	1,174	1,452	
- Rem. (%)	50.8	48.3	27.2	
FCOD				-
- Inf. (mg/l)	997	1,880	-	
- Eff.(mg/l)	477	991	-	
- Rem. (%)	52.2	47.3	-	
BOD				20
- Inf. (mg/l)	485	389	649	
- Eff.(mg/l)	48	39	332	
- Rem. (%)	90.1	90.0	48.8	
Color				(2)
- Inf. (SU)	273	322	326	
- Eff.(SU)	66	117	211	
- Rem. (%)	75.8	63.7	35.3	
SS				50
- Inf. (mg/l)	569	823	838	
- Eff.(mg/l)	192	269	366	
- Rem. (%)	66.2	67.3	56.3	

Remark: (1) Thailand industrial effluent standard
(2) not objectionable

The effluent had no smell with acceptable appearance in pale brown color. Some non-easily biodegradable organics still remained, mainly lignin, and resulted in high COD values. The SS removal was not high as compared to HSF else where. During the study, plant growth was normal and totally 3 harvests were done, in which all plants in the hybrid system were cut at 0.15 m above surface. It was found that umbrella-sedges could grow very well in Saa pulping wastewater. The hybrid system's performances are summarized in table 4.

The treatment efficiency of hybrid system decreased with increasing HLRs. The best hybrid system performances were found at run 1 with overall removal efficiency of COD, BOD and color at 72.9, 94.4 and 84.2%, respectively. If Thailand industrial effluent standard is to be met, additional post treatment is required. Based on HLRs in run 1, the participating entrepreneur has to construct VSF and HSF with surface areas of 35.8 and 138 m^2,

Table 4. Hybrid system's performances

Run	HLR (cm/d)		COD			BOD			Color			SS		
	VSF	HSF	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)	Inf. (SU)	Eff. (SU)	Rem. (%)	Inf. (mg/l)	Eff. (mg/l)	Rem. (%)
1	5.0	1.3	2,442	662	72.9	855	48	94.4	419	66	84.2	923	192	79.2
2	13.4	3.4	3,939	1,174	70.2	1,096	39	96.4	455	117	74.3	1,299	269	79.3
3	76.0	59.7	2,534	1,452	42.7	885	332	62.5	395	211	46.6	1,206	366	69.6

respectively. The total treatment plant area will be about 4 times of pulping production area and not available in the entrepreneur's compound. The construction cost will also be unaffordable. Although there are various treatment options with less space such as ozonation, activated carbon adsorption, etc., it is unlikely to be chosen due to high operation and maintenance cost. The average producer has 3 - 4 staffs including the owner with limited technical skills. Since household producers can not be enforced by law, the implementation strategy must base on their consensus and local constraints. According to the meeting of stakeholders, i.e. authors, municipality staffs, producers, environmental staffs, etc., partial treatment at affordable cost is the better alternative. The average characteristics of pulping wastewater for BOD and color are set at 1,000 mg/l and 450 SU, respectively. From interpolation of table 2 and 3, the HLR of VSF is selected at 45 cm/d with expected BOD and color removal of 40 and 25 %, respectively. The VFS effluent should have BOD and color at 600 mg/l and 338 SU, respectively. The HLR of HSF is suggested at 40 cm/d with BOD and color removal of 60 and 40 %, respectively. The hybrid system at HLRs of VSF/HSF at 45.0/40.0 cm/d will have removal efficiency of BOD and color at 76 and 55%, respectively. The effluent BOD concentration is within 240 mg/l. The dye pigments will be mostly degraded leaving effluent with pale brown color, about 203 SU, which is in acceptable appearance (Figure 6).

The hybrid system implementations have been conducted since May 2008 in cooperations with 5 entrepreneurs in Tonpao village. They use Saa bark either at 25 or 150 kg/d. The authors provided the construction drawings. The Office of SMEs (Small and Medium Entrepreneurs) Promotion, Ministry of Industry provides 50% subsidy for the construction through Tonpao municipality while coauthor from Chiang Mai Rajabhat University will supervise the construction as well as system monitoring. The prototype will be used for further dissemination to pulp producers in other areas.

Figure 6. Photograph of effluent color from hybrid system at 203 SU

Conclusions

The VSF treatment efficiency decreased with increasing HLRs. The performances at HLRs 1.3 - 25.2 cm/d in terms of COD and color removal were rather low at 39.1 - 50.2% and 14.1 - 50.2%, respectively. The BOD removal was slightly higher, in the ranges of 43.3 -76.3%. The VSF is suitable as pretreatment step. The hybrid system, at HLRs of VSF/HSF at 5.0/1.3 and 13.4/3.4 cm/d, could treat pulping wastewater to an acceptable level but still exceeded industrial effluent standard. Due to various constraints, partial treatment by hybrid system is suggested.

Acknowledgment

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