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MICROCOSM EXPERIMENTS ON A COCONUT-FIBRE BIOFILM TREATMENT SYSTEM TO EVALUATE WASTE WATER TREATMENT EFFICIENCIES

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ABSTRACT: Interest in utilization of locally available biomasses as biofilm support media for wastewater treatment in developing countries is increasing. In this study, microcosm experiments on a coconut-fibre biofilm treatment system were carried out to evaluate wastewater treatment efficiencies in the laboratory using two wastewaters, synthetic sewage and leachate, with different pollutant loads. Three coconut-fibre conditions were set as a single bundle (low fibre density: LFD), two bundles (high fibre density: HFD), and no coconut fibre (blank). The wastewater was first circulated in the system for six weeks (circulation stage) and then discharged from the treatment tank for 7–24 weeks (treatment stage). Water quality parameters of effluents, pH, DO, EC, BOD, COD, TC, and TN, were measured at one-week intervals, and the sedimented sludge in each treatment tank was collected to determine C, N, and P contents. Results showed effective reductions in BOD and COD in the LFD and HFD conditions for the synthetic leachate, indicating that the coconut fibre contributed to the treatment of wastewater. On the other hand, the fibre density had less or no effect on the reduction of water quality parameters in the synthetic sewage. For both synthetic sewage and leachate, the C and N consumptions generally increased in the order of blank, LFD, and HFD. In particular, sludge sedimentation contributed to C consumption under the HFD condition.

Keywords: Sewage, Landfill leachate, Coconut-fibre, Biofilm treatment, Sri Lanka

1. INTRODUCTION

Water pollution can be defined as the extensive presence of substances and organisms dissolved or suspended in water that cause serious health and environmental impacts. Improper management and treatment of wastewater cause significant environmental degradation in developing countries. In Sri Lanka, the amount of sewage collected has been increasing with the increase in the number of separate toilets since the 1980s, but most of the collected sewage was directly discharged in vacant lands, forests, streams, or excavated pits without any treatment [1]. Furthermore, a common practice is open dumping of collected solid waste without any leachate treatment [2], [3]. Thus, improper management and treatment of wastewater cause surface and groundwater pollution and trigger numerous resident complaints in Sri Lanka.

Interest in the utilization of locally available biomass resources for application as natural biofilm support media for wastewater treatment is increasing due to its low cost and low technology. A coconut-fibre biofilm treatment system (COTS), for example, has been introduced by some local authorities in Sri Lanka to treat the collected sewage and leachate at waste disposal sites [1]. COTS have been operated by Balangoda and Kuliyapitiya Urban Councils since 2009 and by the Tangalle Urban Council since 2012 to treat collected sewage. In addition, a COTS has been operating to treat the collected leachate from an engineered waste landfill at Nuwara Eliya Municipal Council since 2004. The results of water analyses in 2012 showed COD, BOD_5, and NH_4^+-N values decreased from inlet to outlet at all sites [1]. It has been reported that COTS performed well for treating wastewater under proper maintenance and operation. However, the mechanisms of wastewater treatment in COTS and quantitative analyses for designing and optimizing the system are not fully understood. In this study, we carried out microcosm experiments in the laboratory using both synthetic sewage and leachate to evaluate the wastewater treatment efficiencies of COTS.

2. MATERIALS AND METHODS

2.1 Materials

Because coconut (*Cocos nucifera* L.) fibre is rich in hard organic matter with high specific surface area and wetting ability, it seems suitable for microorganism adhesion and biofilm formation. Coconut fibre is a waste byproduct of coconut processing and is abundantly available in Sri Lanka.

The preparation of synthetic sewage in this study was adapted from data measured at Balangoda Urban Council in Sri Lanka [1] and reported data [4]. The synthetic leachate was prepared to meet the following objectives: 1) to be more representative of real leachate in Sri Lanka, and 2) to be stable during the experiment (two weeks). The preparation of synthetic leachate in this study was adapted from reported data [5] and previous studies with some modifications [6], [7]. Water qualities of supplied synthetic sewage and synthetic leachate are shown in Table 1.

2.2 Experimental apparatus

The experimental apparatus for the microcosm experiment consisted of a supply tank for synthetic sewage or synthetic leachate, a peristaltic pump, and a treatment tank (0.012 m^3 volume) with inlet and outlet valves (Fig. 1). A bundle of coconut fibre (~0.2 m length) was used as a biofilm support medium. The coconut fibre was put inside the treatment tank under one of two conditions: low fibre density (LFD; a single bundle per treatment tank) or high fibre density (HFD; two bundles per treatment tank). As a control, a container without a coconut-fibre bundle was also used in the experiment. The synthetic sewage or synthetic leachate solution was pumped into the treatment tank from the supply tank by a peristaltic pump at a rate of 870 cm^3/day (two-week retention time). Lighting with illumination intensity of 4,730 lux was maintained at the top of treatment tank for 12 hours per day, and the temperature was maintained at 20°C.

2.3 Experimental procedures

The schedule of microcosm experiments was divided into two flow stages, the circulation stage and the treatment stage (Fig. 1). For the circulation stage, a mixture of raw wastewater from a sewage treatment plant in Saitama City, Japan, and synthetic wastewater (1 L of raw wastewater and 35 L of synthetic wastewater) was initially prepared and recycled through the microcosm system to accelerate biofouling of the bundle of coconut fibre. The circulation period was set to 42 days.

Water samples in the supply tank and treatment tanks were collected during the circulation stage on a weekly basis for analysis of basic water quality parameters such as chemical oxygen demand (COD_{Cr}; hereafter just COD), biological oxygen demand (BOD_5), total carbon (TC), total phosphorus (TP), total nitrogen (TN), pH, dissolved oxygen (DO), oxidation reduction potential (ORP), and electrical conductivity (EC). Standards method were used to analyze BOD, TP, TN (Water test kit, Kyoritsu chemical check lab, crop., Japan) and COD (HACH DRB 200, USA). TOC analyzer (TOC-V-CSH, Shimadzu, Japan) was used to measure TC. It is noted that TP was measured only for the synthetic sewage conditions. After completion of the circulation stage, water and sludge in the supply tank and treatment tank were removed. Carbon and nitrogen contents of the coir fibre and sludge settled at the bottom of the treatment tank were quantified.

For the subsequent treatment stage, the microcosm system was first filled with the synthetic wastewater solution. Then, the synthetic sewage/synthetic leachate solution was supplied continuously from the supply tank. During the treatment stage, water quality parameters were measured once a week.

Table 1 Water qualities of supplied synthetic wastewater

Wastewater		Synthetic sewage		Synthetic leachate	
Pollutant load		Low	High	Low	High
pH		8.2	7.6	8.1	7.8
DO	mg/L	5.0	2.9	0.2	0.1
EC	mS/m	5.64×10^2	1.34×10^3	7.10×10^2	1.79×10^3
BOD	mg/L	1.45×10^3	5.93×10^3	9.38×10^2	1.43×10^4
COD	mg/L	1.77×10^3	6.36×10^3	1.72×10^3	2.14×10^4
TC	mg/L	9.55×10^2	3.42×10^3	7.05×10^2	6.49×10^3
TOC	mg/L	5.29×10^2	3.02×10^3	4.06×10^2	5.57×10^3
TN	mg/L	7.36×10^2	2.59×10^3	6.40×10^2	6.91×10^2
TP	mg/L	2.58×10^2	7.03×10^2	7.80×10^2*	7.80×10^2*

*Calculated value from added K_2HPO_4 [3].

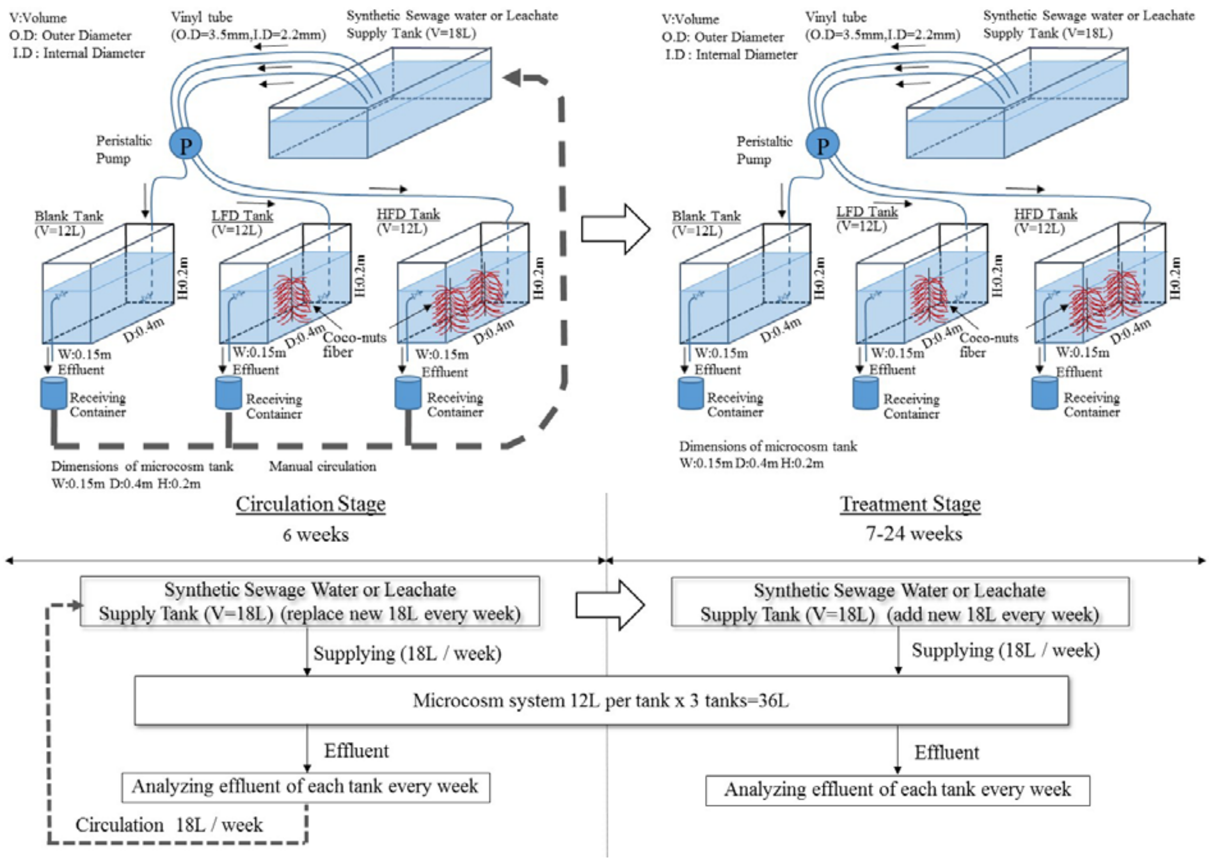

Fig. 1 Schematics of microcosm experiment

3. RESULTS AND DISCUSSION

3.1 Changes in water quality parameters during circulation and treatment stages

Figures 2 and 3 exemplify the variations in BOD, COD, BOD/COD, TC, and TP of effluents in microcosm experiments at high pollutant load conditions. For the synthetic sewage (Fig. 2), the concentrations of water quality parameters did not vary much during the circulation and treatment stages except for TP (the concentrations of TP dropped when the treatment began). Less and no effects of the coconut fibre on the reduction in the concentrations were observed, and the concentrations of water quality parameters did not vary among LFD, HFD, and blank conditions.

For the synthetic leachate (Fig. 3), the effect of coconut fibre on reduction in the concentrations of water quality parameters, i.e., reductions in the concentration became higher in the order of HFD, LFD, and blank conditions. In particular, the reduction in COD was more significant for the conditions of HFD and LFD compared to the blank condition (which concentration became close to the inflow concentration).

3.2 Removal % changes in water quality parameters under circulation and treatment stages

The removal % in the treatment stage of each parameter was calculated using the following equation, and averaged values of removal % from four weeks at the end of treatment stage are summarized in Table 2. The previously reported values of removal % from the field COTS [1] and stabilization pond systems [8]–[10] are shonwn in the table.

$$\text{Removal \%} = \frac{\text{Inflow (mg/L)} - \text{Outflow (mg/L)}}{\text{Inflow (mg/L)}} \times 100 \quad (1)$$

Generally removal % of all parameters in the synthetic leachate became higher than those for the synthetic sewage. In particular, the removal % of BOD and COD from the synthetic leachate in LFD and HFD conditions became much higher than those of the blank, indicating that coconut fibre in the treatment tank contributed to the treatment of wastewater. The removal % of BOD and COD in low load conditions became higher than those in high load conditions, implying that the proper control of pollutant loads is useful to improve the treatment of leachate in COTS.

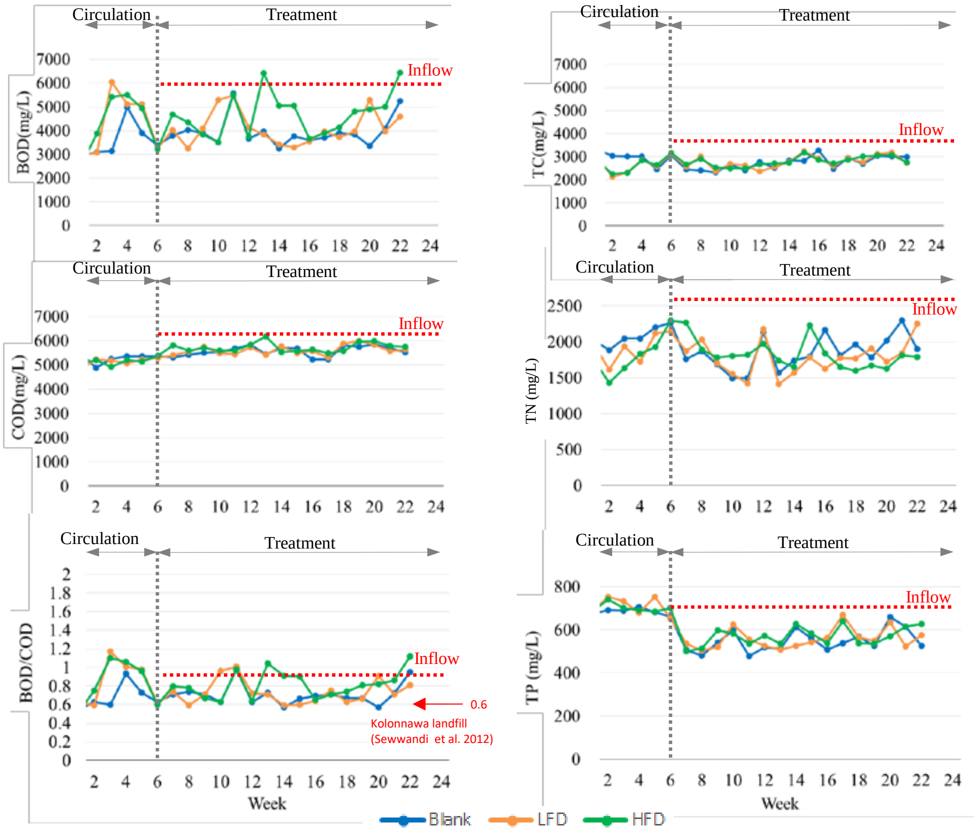

Fig 2: Variations in BOD, COD,BOD/COD, TC, TN, and TP of the effluents during circulation and treatment stage of synthetic at high pollutant load

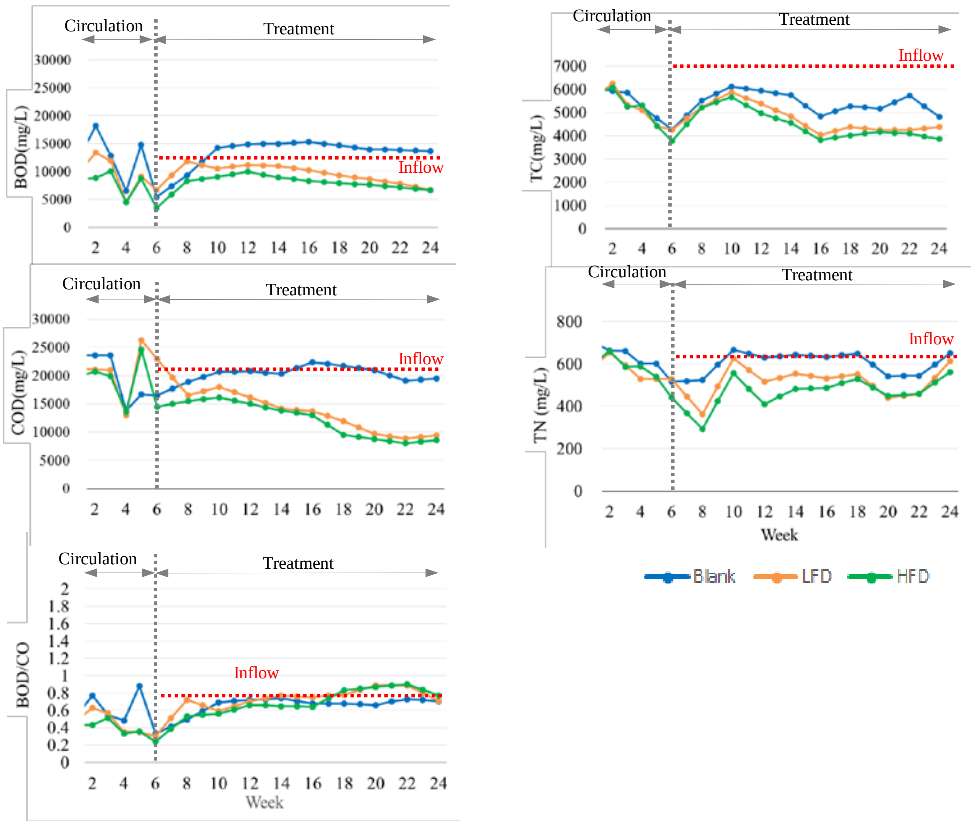

Fig. 3 Variations in BOD, COD, BOD/COD, TC, and TN of effluents during the circulation and treatment stages for synthetic leachate at high pollutant load

Table 2 Removal % of BOD, COD, TC, TN and TP for synthetic sewage and leachate

Pollutant load	Treatment tank	Synthetic sewage					Synthetic leachate			
		BOD (%)	COD (%)	TC (%)	TN (%)	TP (%)	BOD (%)	COD (%)	TC (%)	TN (%)
Low	Blank	9.9	11.0	5.8	5.9	15.4	59.8	55.9	26.7	8.2
	LFD	13.7	10.0	7.3	13.3	10.3	85.6	67.7	40.9	19.1
	HFD	13.5	5.8	8.8	14.7	4.7	87.4	71.2	49.4	23.9
High	Blank	33.3	12.1	19.5	28.8	21.8	6.1	6.3	28.2	12.0
	LFD	30.5	11.6	18.6	31.8	20.5	35.9	41.4	37.8	26.1
	HFD	22.1	10.2	18.2	30.9	18.3	45.2	46.5	41.2	32.9
Field COTS Sato et al., 2013		78.2*	58.9*	-	67.5*	53.8*				
Stabilization pond system at field										
Kayombo et al., 2002		-	66-71	-	-	-				
Naddafi et al., 2009		71	71	-	-	-				
Farzadkia et al., 2014		74.6	76.3	-	-	-				

*Averaged values in August 2010 and 2012

For the synthetic sewage, on the other hand, the values of removal % in LFD and HFD conditions were relatively low compared to the previously reported values, indicating that the coconut fibre contributed little or nothing to the treatment of wastewater. Opposite to the results of synthetic leachate, the removal % of pollutants in high load conditions became generally higher than those in low load conditions. This would also imply that the proper control of pollutant loads is effective to improve the treatment of sewage in COTS.

3.3 Consumptions of C, N, and P in microcosm experiments

In order to clarify the removal efficiencies of C and N in the microcosm COTS, the consumptions of C, N, and P per unit volume of microcosm (unit volume of the treatment tank) per week [mg/L of microcosm/week] were calculated by using TC and TN values of inflow solutions and effluents and C and N contents of collected coir and sludge samples. For the synthetic sewage, the consumption of P was also calculated. An example of the calculation for C consumption under the circulation stage is shown in Table 3. In the example, the HFD condition consumed the most C (94.4 mg/L of microcosm/week) compared to other LFD and blank conditions.

Table 4 summarizes the calculated C, N, and P consumption values for all tested conditions. The consumptions of C, N, and P in the microcosm COTS varied depending on both fibre densities and pollutant loads of wastewater. The C and N consumptions in the microcosm became more effective at HFD conditions for both low and high pollutant loads in wastewater. For both synthetic sewage and leachate, the C consumptions under the treatment stage became approximately double those under the circulation stage except for the low pollutant load of the synthetic sewage. The C consumptions for the synthetic leachate were greater than those for the synthetic sewage under both circulation and treatment stages; i.e., the C consumptions for the synthetic leachate became around 2–3 times those for the synthetic sewage at low pollutant load conditions and around 3–7 times higher than those for the synthetic sewage at high pollutant load conditions.

N consumptions during the treatment stage also became higher than those during the circulation stage. HFD gave the highest C consumption values among tested conditions, and they became around 1.8 and 1.5 times higher than those for blank (control) and LFD conditions, respectively. This implies that the higher coconut-fibre condition contributed to the C consumption in the microcosm COTS.

Table 3 Sample calculation of C consumption

No	Parameter	Symbols in Calculation	HFD	LFD	Blank
1	TC inflow (mg/L)	A	$3.42x10^3$	$3.42x10^3$	$3.42x10^3$
2	TC outflow (after 42 days) (mg/L)	B	$3.16x10^3$	$3.13x10^3$	$3.06x10^3$
3	Total C consumption (mg/L)	C=A-B	$2.63x10^2$	$2.95x10^2$	$3.62x10^2$
4	Volume of leachate in circulation period (L)	D	12	12	12
5	Initial C in solution- final C in solution (g)	E=(C x D)/1000	3.2	3.5	4.3
6	Accumulated Sludge mass (g)	F	17	18	11
7	C content in sludge (%)	G	7.1	8.4	5.5
8	C content in accumulated sludge (g)	H=(F x G)/100	1.2	1.5	0.6
9	Dry mass of coir fibre(g)	I	48.6	24.6	-
10	C content of coir fibre after recirculation (%)	J	45.8	46.8	-
11	C content in raw coir fibre (%)	K	40.8	40.8	-
12	Accumulated C mass in coir fibre (g)	L=(J-K) x J/100	2.4	1.5	-
13	Total used C in recirculation phase for 42 days(g)	M=E+H+L	6.8	6.5	5.0
14	Volume of microcosm tank (L)	N	12	12	12
15	C consumption (mg/L of microcosm/week)	O=M/N/ 42 days x7 days x 1000	94	90	69

Table 4 C, N, and P consumptions in microcosm experiments

Pollutant load	Stage	Treatment tank	Synthetic sewage						Synthetic leachate			
			C		N		P		C		N	
			Consumption (mg/L of microcosm / week)	% in sludge	Consumption (mg/L of microcosm / week)	% in sludge	Consumption (mg/L of microcosm / week)	% in sludge	Consumption (mg/L of microcosm / week)	% in sludge	Consumption (mg/L of microcosm / week)	% in sludge
Low	Circulation	Blank	42	15	29	1.7	10	4.7	73	17	57	1.7
		LFD	54	17	25	2.5	9	4.7	95	20	70	2.5
		HFD	72	17	24	2.3	7	4.2	$1.0x10^2$	20	70	2.3
	Treatment	Blank	34	6.0	17	4.2	12	5.7	$1.2x10^2$	12	28	0.4
		LFD	54	9.2	44	4.7	11	5.1	$1.7x10^2$	13	77	0.4
		HFD	68	7.8	51	3.6	15	4.7	$2.0x10^2$	12	88	0.2
High	Circulation	Blank	69	5.5	57	1.6	14	4.6	$4.8x10^2$	13	37	1.0
		LFD	90	8.4	78	1.8	20	4.3	$6.2x10^2$	18	44	1.5
		HFD	94	7.1	51	1.5	11	4.3	$6.9x10^2$	17	56	1.3
	Treatment	Blank	$2.2x10^2$	3.7	$2.5x10^2$	1.6	24	4.3	$8.7x10^2$	21	93	0.9
		LFD	$3.7x10^2$	4.0	$1.2x10^2$	1.3	33	4.4	$1.1x10^3$	22	94	1.0
		HFD	$3.7x10^2$	5.3	$2.9x10^2$	1.8	13	3.9	$1.3x10^3$	20	92	0.7

It is noted that the C % in sludge for LFD and HFD would not vary much among tested conditions, indicating that the C removal in sludge would not directly contribute to the higher C consumption in the HFD condition. It is also noted that the COTS microcosm for the sewage treatment contributed less to the P consumption, similar to the results from the field COTS [1], and implying that further improvement is necessary to achieve the effective removal of P.

4. CONCLUSIONS

Based on the results of laboratory tests, the microcosm COTS contributes to the reduction of water quality parameters, such as BOD and COD, especially of the synthetic leachate, and higher consumptions of C and N can be expected in the conditions of higher coconut-fibre density due to higher sludge sedimentation. The removal % of pollutants was dependent on the load conditions and the proper control of pollutant loads is effective to improve the treatment efficiencies of sewage and leachate in COTS.

Further quantitative analyses are needed to clarify the wastewater treatment efficiencies such as biomass yield and oxygen requirements and to improve the removal efficiency of P in the COTS.

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