Nutrient recovery from anaerobic digester liquid effluent using ornamental aquatic macrophytes

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Abstract. Anaerobic digestion (AD) which treat food waste is a waste-to-energy method that produces liquid effluent. This by-product, known as digestate, contains high nutrients that could be recovered using ornamental aquatic macrophytes in a constructed wetland system. This study investigates the capacity of nutrient recovery of *Canna indica*, *Iris pseudocarus*, and *Typha latifolia* from liquid digestate, together improving the quality of AD effluent. Constructed wetland with *T. latifolia* effectively removed TSS and COD to meet the wastewater quality standards (TSS = 71 mg/L, COD = 56.735 mg/L). *C. indica* removed up to 72% N as the highest N removal efficiency, and recovered most of N, even though it still needs longer detention time to meet the standard. *I. pseudocarus* removed up to 98% P yet the average TP level in the plant was slightly above *T. latifolia*. The result shows that nutrient recovery using constructed wetland improves the effluent quality within short operation period, meanwhile *C. indica* and *I. pseudocarus* as ornamental aquatic macrophytes also added the aesthetic value to the environment.

1. Introduction

Anaerobic digestion (AD) is a well-known method in waste-to-energy (WTE) system to treat organic waste, such as food waste, which also act as the problem solver of food waste generation. Researchers has been doing this method for reducing the rate of waste generation and producing energy. Meanwhile the effluent generated at the end of the process known as digestate is a by-product that needs to be treated [1]. Digestate which has two forms, solid (fibre) and liquid (liquor), contains high nutrient that could act as a pollutant when no post-treatment applied [2]. Due to the high nutrient content of digestate, it must be treated before disposing to prevent unwanted matter on the environment. Solid fraction/ fiber digestate has 8.8—13.0 kg/t DS of total nitrogen (TN), as for the liquid fraction/ liquor digestate has 4,000—6,000 mg/l of TN, 7,500—10,000 mg/l of biological oxygen demand (BOD), 90,000—115,000 mg/l of chemical oxygen demand (COD), and 5,000—63,000 mg/L of total suspended solid (TSS) content [2, 3].

The characteristic of digestate made it as a valuable nutrient source, yet not many technologies are implementable in developed countries. There are chemical and physical treatment could be applied towards digestate, such as alkaline stabilisation (chemical), thermal hydrolysis (physical), or centrifuge thickening (physical). But for chemical treatment, it has potential for releasing odour, could be unsuitable for all soil types and requires high chemical. As for the physical treatment, it requires high temperature, pressure, energy, yet it also still needs to dispose the liquor [4].

One other way to treat digestate is by biological treatment, using the nutrient recovery method, which not only could recover nutrients from digestate by plant uptake, but also creates a cleaner environment by making a friendly post treatment product (low nutrient, BOD and COD content). Nutrient recovery of digestate that has been done was only up to composting (biofertilizer), mostly on solid form, but it was not good enough to compete with synthetic fertilizers unless it is integrated with an agriculture industry which use AD technology as well [2, 4]. Plants, particularly aquatic macrophytes, has a reputation in nutrient removal system, such as constructed wetland. Aquatic macrophytes are type of plants which has a macro form, and lives in a wet ecosystem [5]. The vegetation that are quite popular in here is *Canna indica*, *Iris pseudocarus*, and *Typha latifolia*. Each of these ornamental aquatic macrophytes recovered the nutrients from liquor state as nutrient uptake which will be the source of their development.

Horizontal subsurface flow was the chosen type of the constructed wetland used in the research [6]. This system was the best option as the constructing location was near the campus which could prevent smell from the influent (since it flows in the subsurface), near from water and energy source, and fairly manageable. The site was also for adding the aesthetic view.

C. indica is one of the most popular ornamental aquatic macrophyte used in the wastewater treatment in a wetland system. As for treating domestic wastewater, *C. indica* could be used as an efficient nutrient removal up to 84% for nitrogen removal and 92% for phosphorus removal, which could create a healthier environment at the end of the treatment [7]. The selection of the vegetation was based on literature that mentioned emergent type is the most productive one from the other aquatic macrophyte plants. The other reason was also for the availability in the country, price and aesthetic [8]. With those capabilities and advantages, *C. indica* could be more likely used as a nutrient recovery agent for substances such as liquid products of organic waste treatment which has similarities with domestic wastewater; high nutrient content. This study focused on how ornamental aquatic macrophytes could recover nutrient and contribute in improving the effluent quality as a post-treatment for liquid digestate. *C. indica* was compared to two other ornamental aquatic macrophtyes, *I. pseudocarus* and *T. latifolia*, which are also common to be used as aesthetic plants.

2. Method

2.1. Operation and sampling method

The operation flow started from the AD reactor to the influent storage, and the influent later will be distributed to three beds (Figure 1). The operational time was done in 10 weeks; acclimatization (A) stage in 7 weeks and feeding (F) stage in 3 weeks. Both stages (A and F) started during the morning time (10 AM); flowing the influent inside the bed. Sampling was done three times a week (every two days) after the acclimatization stage.

Sampling was done in every stage in a certain period range. The A stage effluent sampling was done 3 times for each bed, and the F stage was done 2 times for each bed (HRT = 11 days) [9]. As for the plants sampling was done 2 times; once after the A stage was done, and once at the end of the operation time. Each sample was kept in the freezer until it was sent to the lab for checking the parameters.

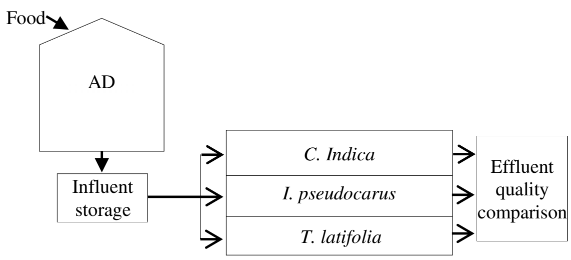

Figure 1. Operation flow

2.2. Influent characteristic, CW design and laboratory analysis

The constructed wetland influent was from an anaerobic digester which treat food waste [10, 11]. Effluent from the digester were pretreated by dilution (4x) to provide an influent with a BOD_5 characteristics $\pm$ 400 mg/L. This characteristic must be reach for the survival of the macrophyte itself [10].

Table 1. Characteristics of the influent

Periode	TSS (mg/L)	COD (mg/L)	BOD_5 (mg/L)	TN (mg/L)	TP (mg/L)
A1	2393.75	2253.165	420	617.219	305.563
A2	-	2626.583	275	658.808	401.890
A3	-	-	255	580.828	388.856
F1	6718.75	5158.228	530	669.948	37.943
F2	-	5039.558	520	649.154	3.983

A = acclimatization; F = feeding

As for the land used for each bed is 170 × 80 × 70 cm (length : width : depth), with planting area 120 × 60 cm (length : width). *C, indica*, *I. pseudocarus* and *T. latifolia* were the experimented object in the study. Sediment for the bed are as followed: top layer: clay (20 cm), middle layer: sandy loam (15 cm), and bottom layer: coarse sand (15 cm). In the inlet and outlet of the bed were used gravel (each side 15 cm)

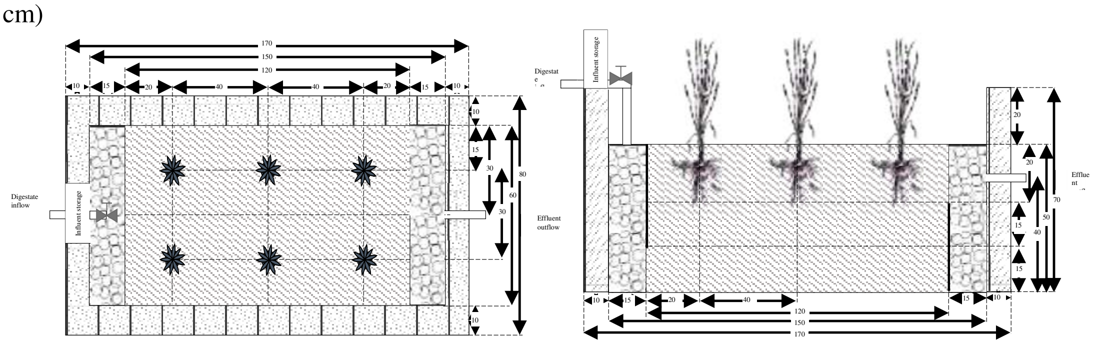

Figure 2. Top (left) and side (right) view of the HSSF CW design (scale in centimeter)

The parameters that were analyzed in this research are total suspended solid (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD_5), total nitrogen (TN), and total phosphorus (TP). TSS content were tested on the initial influent flow and the last effluent sampling. BOD_5 was observed only on the influent. COD was check on all samples (influent and effluent), while TN, and TP were checked on influent, effluent, and plants. Those parameters will later be analysed to know the removal rate of COD, N, P, and nutrient uptake by each plant as the act of recovering nutrients.

2.3. Data analysis
The data which were gained from the study will be analysed later on by doing these steps.

1. Calculating each parameter removal (TSS, COD, and nutrient) by each plant using an equation.

$$\%\text{parameter removal}=\left(\frac{\text{parameter}_{\text{input}}-\text{parameter}_{\text{output}}}{\text{parameter}_{\text{input}}}\right)\text{mg/L x }100\% \quad (1)$$

2. Calculating the nutrient (N and P) uptake by each plant.

$$\text{Nutrient uptake (g/m}^2\text{)} = \left(\text{Nutrient}_{\text{F}}(\%)\text{x}\frac{\text{biomass F (g)}}{\text{planting area (m}^2\text{)}}\right) - \left(\text{Nutrient}_{\text{A}}(\%)\text{x}\frac{\text{biomass A (g)}}{\text{planting area (m}^2\text{)}}\right) \quad (2)$$

3. Result and Discussion
3.1. TSS removal
TSS content was check twice, at the end of A stage and the beginning of F stage. In table 2, the highest removal efficiency was shown by *T. latifolia* with 98.65% and the least was by *C. indica* with 95.74%.

Table 2. TSS content and removal in each effluent

Content in bed effluent (mg/L)			Removal (%)		
C. indica	*I. pseudocarus*	*T. latifolia*	*C. indica*	*I. pseudocarus*	*T. latifolia*
286	128	91	95.74%	98.09%	98.65%

C. indica had the least TSS removal efficiency than the other plants while showing a good growth performance (lots of shoots and leaves). *I. pseudocarus* growth was not as good as the other species (withered) during the A stage, yet has better growth development in F stage which made the TSS content lower than the A stage. However, each plant passed effluent quality for aquaculture, farms, plants irrigation and other purposes with the limitation of TSS $\leq$400 mg/L [13].

3.2. COD removal

Table 3. COD content and removal in each effluent

Periode	Content in bed effluent (mg/L)			Removal (%)		
	C. indica	*I. pseudocarus*	*T. latifolia*	*C. indica*	*I. pseudocarus*	*T. latifolia*
A1	750.000	1531.650	105.700	66.71	32.02	95.31
A2	118.350	629.110	99.370	95.49	76.05	96.22
A3	-	-	-	-	-	-
F1	235.440	755.700	20.797	95.44	85.35	99.60
F2	2.201	16.887	1.071	99.96	99.66	99.98

The COD measurement was done on the A1, A2, F1, and F2 stages. Based on the result in table 3, the lowest COD content was conducted by *T. latifolia* bed with the average 56.735 mg/L, also with the highest COD removal efficiency = 97.78%. Regarding to the regulation, only the bed planted with *T. latifolia* could produce effluent with the quality near two the 3rd class of wastewater classification (50 mg/L), while *C. indica* still need extra time to reduce the COD content to reach the 4th class wastewater (100 mg/L) [13].

3.3. N removal

Table 4. N total content and removal in each effluent

Periode	Content in bed effluent (mg/L)			Removal (%)		
	C. indica	*I. pseudocarus*	*T. latifolia*	*C. indica*	*I. pseudocarus*	*T. latifolia*
A1	194.740	223.555	235.735	68.45	63.78	61.81
A2	177.213	223.407	241.528	73.10	66.09	63.34
A3	1204.668	222.070	187.759	-	61.77	67.67
F1	158.201	192.215	257.272	76.39	71.31	61.60
F2	189.393	237.963	165.182	70.82	63.34	74.55

Table 4 shows that the effluent from every bed has lower N total content than the influent in table 1. This shows that N removal process has occurred in the constructed wetland system by each macrophyte. Looking at the result itself, the removal efficiency hasn't reach 90%, which is normal since the operation time was quite short for the constructed wetland to conduct a stable performance. However, there was an anomaly result on period A3. Seems like the result was inaccurate due to the sampling process since the other samples show a quite similar result. The efficiency calculation shows that *C. indica* could remove nitrogen up to 72.19%, the highest N removal efficiency among the other macrophytes in the study. Even though the influent's nitrogen content wasn't as high as the literature mentioned, but *C. indica* has the performance to improve the quality of the effluent. *I. pseudocarus* and *T. latifolia* shows similar efficiency performance, lower than *C. indica*. However, it still shows improvement to the effluent quality. The regulation state that wastewater that could be reuse for plant irrigation must meet 20 mg N/L, while the effluent has 20x N content and need further treatment.

3.4. P removal

Table 5. P total content and removal in each effluent

	Efluen Bed CW (mg/L)			Removal (%)		
	C. indica	*I. pseudocarus*	*T. latifolia*	*C. indica*	*I. pseudocarus*	*T. latifolia*
A1	1.100	4.953	0.810	99.64	98.38	99.73
A2	0.781	3.504	0.897	99.81	99.13	99.78
A3	55.467	2.809	2.375	85.74	99.28	99.39
F1	1.071	1.535	20.797	97.18	95.95	45.19
F2	2.201	16.887	1.071	44.74	-	73.11

The lowest average of P total content was generated by *T. latifolia* bed = 5.190 mg/L, yet *I. pseudocarus* shows the highest removal efficiency = 98.18% with the average P total content = 5.938 mg/L. While TSS, COD, and N removal were inclined to *T. latifolia* and *C. indica* positive results, P removal was inclined to *I. pseudocarus*. Due to the wastewater quality standards, *T. latifolia* dan *I. pseudocarus* almost reach the peak level (5 mg/L), while *C. indica* still contains 2x than what must be determined.

3.5. N and P uptake

C. indica shows a significant result for the N uptake, and has similar P uptake with *T. latifolia*. *C. indica* N uptake reached 166.39 g/m^2, which is 4.25x higher than *I. pseudocarus*, and 5.37x higher than *T. latifolia*. The gap in N uptake is exceptionally large, knowing that the initial biomass of each plants is not quite different. As for the P uptake, *T. latifolia* shows the most significant result by uptaking 16.13 g/m^2 P during the operation.

Table 6. N and P uptake by each macrophyte

Periode	TN (mg/L)			TP (mg/L)		
	C. indica	*I. pseudocarus*	*T. latifolia*	*C. indica*	*I. pseudocarus*	*T. latifolia*
A	28.53	20.36	25.08	0.78	0.62	0.74
F	194.92	59.51	56.04	15.61	6.63	16.87
Total uptake	166.39	39.15	30.96	14.82	6.02	16.13

This result shows on the plant growth/ development, which *C. indica* has the fastest leaves and flower growth, while *I. pseudocarus* has weak roots yet it kept flowering every once in 2 weeks. Morphology of *T. latifolia* showed the nutrient content as mentioned in the table; lack of TN content since the stem color was brown-yellowish, yet the shoots kept growing around the parent plant (increase in TP content).

3.6. Environment quality improvement

The data shows significant differences between influent and effluent quality performed by each plant. The TSS, COD, and TP content reduced with quite high efficiency removal percentage, while for TN it shows above the middle range removal efficiency. Following the regulation for wastewater quality standards, the TSS and COD of the AD effluent already meet the requirement, yet for TN and TP are almost there. The system does require dilution indeed for the plant growth reason (BOD content) [12], this must be solved by other pre-treatment to use less clean water, bearable enough for plants to load, yet suitable to be source of nutrients. However, within the short period, it was able to show a significant content level decrease of each parameter.

4. Conclusion

Nutrient recovery by ornamental aquatic macrophyte in a constructed wetland system could be a solution for treating the end-of-waste of AD to improve the environment quality. TSS content in the effluent from each bed has meet the requirement of the wastewater quality (TSS = $\leq$400 mg/L); *C. indica* = 181 and mg/L, *I. pseudocarus* = 223 mg/L, and *T. latifolia* = 71 mg/L. For COD level, *I. pseudocarus* and *C. indica* are beyond the standard (733.337 and 276.498 mg/L, respectively), only *T.*

latifolia (56.735 mg/L) who meets the quality standard ($\leq$100 mg/L). *C. indica* removed N up to 72.19% from digestate, while *T. latifolia* and *I. pseudocarus* removed 65.79% and 65.26%, respectively. TN removal, it hasn't meet the standard yet, but the efficiency was above the middle range, and even though *I. pseudocarus* has the highest P removal efficiency, the average TP content is still higher than *T. latifolia*.

This study showed that all of the experimented plants could improve the effluent quality by recovering nutrients from liquid digestate, but the best performance goes to *C. indica*. Overall, the bed of *T. latifolia* performed better than *C. indica* and *I. pseudocarus*, yet *C. indica* and *I. pseudocarus* recovered more nutrients and have better morphology than *T. latifolia*. In terms to gain both improving water quality and adding the aesthetic value to the environment, further studies need to be done. This study shows that nutrient recovery method using constructed wetland does improve the effluent quality within the short operation period (10 weeks), yet for having better quality (less COD and TN level), longer period is recommended to have stable performance by the wetland. *C. indica* and *I. pseudocarus* as ornamental aquatic macrophytes also added the aesthetic value to the environment.

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