Original Articles

Potential Study of Using Earthworms as an Enhancement to Treat High Strength Wastewater

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Abstract

The aim of this research was to preliminarily investigate the potential of earthworms to reduce clogging by introducing into the lab-scale wetland-like reactors receiving high strength wastewater, which were swine wastewater in Thailand, and domestic wastewater in Germany. The preliminary results indicated that every unit with earthworms had no sign of clogging regardless of the type of wastewater, whereas clogging was the case in the units without earthworms receiving swine wastewater. Both studies reflected similarity, which exhibited little treatment in every microcosm. It could be implied that earthworms could thrive within the wetland body due to the survival rate of 50% for the one receiving domestic wastewater and higher than 85% for the one receiving swine wastewater. It is possible that the competition for food among earthworms is higher in domestic wastewater than in swine wastewater. With this technique, clogging potential could be reduced. Further scale-up of the experiment is strongly suggested.

Keywords : Clogging, constructed wetland, earthworms, swine wastewater, vermicomposting

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บทคัดย่อ

การศึกษาความเป็นไปได้ในการใช้ไส้เดือนดินเพื่อเพิ่มประสิทธิภาพในการบำบัดน้ำเสียที่มีความสกปรกสูง

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เป้าหมายหลักของงานวิจัยนี้คือ การสำรวจความเป็นไปได้ในการนำไส้เดือนดินมาประยุกต์ใช้กับบึงประดิษฐ์ เพื่อที่จะลดผลกระทบจากการอุดตันโดยใช้ระบบจำลองขนาดเล็ก โดยทำการทดลองกับน้ำเสียสองชนิด คือ น้ำเสียมูลสุกรในประเทศไทย และน้ำเสียเทศบาลในประเทศเยอรมนี ผลการทดลองเบื้องต้นได้ชี้ว่า ไม่มีการอุดตันเกิดขึ้นเลยในกระบอกทดลองที่มีไส้เดือนดิน ส่วนกระบอกที่ไม่ได้ใส่ไส้เดือนดิน จะมีการอุดตันเฉพาะกับน้ำเสียมูลสุกร ในส่วนของคุณภาพการบำบัดน้ำเสีย การทดลองทั้งสองรอบได้แสดงผลออกมาคล้ายกัน คือ มีการบำบัดเกิดขึ้นในระดับไม่สูง ทั้งนี้ไส้เดือนดินสามารถจะเจริญเติบโตอยู่ในบึงประดิษฐ์ได้ โดยมีอัตราการรอดชีวิตอยู่ที่ร้อยละ 50 สำหรับการทดลองกับน้ำเสียเทศบาลและร้อยละ 85 สำหรับการทดลองกับน้ำเสียมูลสุกร ซึ่งมีความเป็นไปได้ว่าเกิดการแข่งขันระหว่างไส้เดือนดินเพื่อแย่งอาหารกันในกรณีของน้ำเสียเทศบาลสูงกว่าในน้ำเสียมูลสุกร จึงทำให้มีอัตราการรอดชีวิตต่ำกว่า กล่าวโดยสรุป มีความเป็นไปได้ที่การอุดตันภายในบึงประดิษฐ์สามารถลดลงได้ด้วยเทคนิคดังกล่าว นอกจากนี้ควรที่จะมีการขยายขนาดของการทดลองเพื่อนำไปใช้ขยายผลในทางปฏิบัติต่อไป

คำสำคัญ : การอุดตัน บึงประดิษฐ์ ไส้เดือนดิน น้ำเสียมูลสุกร การหมักโดยไส้เดือนดิน

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Introduction

There have been high concerns for the problem of swine wastewater in Thailand, as swine farming has undergone a rapid growth in order to feed the fast-increasing population and new culture of diet (TDA, 1997). There are several technologies available, and among them, subsurface-flow constructed wetland appears to draw considerable attention due to its low cost and energy demand. At present there are handfuls of research dealing with this theme undertaken (Prantner et al., 2001; Lee et al., 2004), including one in Thailand, in which a vertical subsurface-flow constructed wetlands (VSFCWs) is put over a horizontal flow bed (Kantawanichkul et al., 2001, 2003). Moreover, it can also be applied in conjunction with the biogas technology to improve the effluent quality.

Nevertheless, one of the major obstacles for the efficient use of subsurface-flow wetland is the potential of clogging, especially in the case of VSFCWs (Blazejewski and Murat-Blazejewska, 1995; Crites and Tchobanoglous, 1998). In this case, the hydraulic conductivity is decreased, reducing the overall treatment efficiency. The susceptibility of this problem rises in accordance with the strength of wastewater. Its conventional mitigation practice is to implement the rest periods (Breen, 1997). However, this will affect the design loading rate of the system in the sense of lowering the loading rate at constant wastewater quantity. And hence it could be implied that more surface area is needed.

One study from Australia reported that earthworms were observed in a number of horizontal subsurface-flow constructed wetlands (HSFCWs) and further research was undertaken (Davison et al. 2005). It revealed that large numbers of earthworms were spotted in the non-clogged reed beds, mainly at the inlet zone. This was led to the hypothesis that earthworms might be the key to prevent the clogging. It was also shown that earthworms were translocating clogging solids in the form of their casts (vermicomposts) from the pores of the gravel to the

surface, which could be used as a soil conditioner. Vermicomposting technology (the use of earthworms to treat solid wastes) has long been applied to treat the swine manure (Edwards et al., 1998; Gunadi and Edwards, 2003; Edwards, 2004) as well as wastewater sludge (Prince et al., 1981). It could be possibly integrated into the VSFCWs.

This paper aims to investigate the potential of earthworms to prevent clogging as well as their survivability to the wetland's substrates. Hence, part of the study in Thailand was undertaken to evaluate the survival tendency of introducing native earthworms, *Pheretima Peguana*, in a lab-scale experiment for the treatment of high-strength wastewater, which in this case is swine wastewater. The work in Germany was carried out based on the experience gained from Thailand in order to find the results while using deeper gravel layer, as well as the more established and popular earthworm species, *Eisenia Fetida*. Apart from the survival rate, wastewater quality was also sampled and presented in this study.

Materials and Methods

The experiment in Thailand was set up by using 6 small-scale reactors made of transparent plastic (10 centimeter (cm) diameter and 20 cm height), with the gravel size of 5-25 millimeter (mm) diameter for 10 cm, and 25-40 mm diameter for 2 cm as a drainage layer. The swine wastewater was taken from†Swine Research Unit Farm, Department of Animal Husbandry, Faculty of Veterinary Science, Chulalongkorn University, Nakornpathom province. It was diluted with deionized water to get a ratio of 1:1, 1:2, and 1:4, in order to observe the maximum threshold level that earthworms can thrive. To make a comparison, there were 2 sets of reactors for each dilution, one with 20 individuals of earthworm (corresponded to around 5 gram, g) and one without. Generally, the use of local earthworms species has been highly encouraged due to several reasons; 1) they have more tolerance to local climatic condition, 2) the use of foreign (imported) species could cause an disruptive impact to the ecological system (Edwards, 2004), and 3) they are easier to find and cheaper to obtain. In this experiment, *Pheretima* spp. was used. This species is local and has been proved to be able to vermicompost the organic wastes in Thailand (Julian et al., 1999). Due to the time constraint, all of the reactors were unplanted.

Hydraulic loading rate (HLR) was set at 8 cm/day (cm/d), which is the maximum value recommended in the German guideline for vertical flow constructed wetland to treat municipal wastewater (ATV, 2004). Because of the extremely high solid content in swine wastewater, this could demonstrate as an extreme case. The reactors were fed twice a day, with the interval of 6 hours in between. The experiment was run for a week. The samples were taken every 2 days. After that, the numbers of earthworms sustained within each reactor were hand-counted.

The preliminary study in Germany was carried out using 4 small-scale cylinders with 10 cm diameter located in the 20°C temperature-controlled room and has been divided into 2 sets. Comparing to the microcosms (the reactors used in this study, in Thailand) smaller size-difference of gravel was selected. The gravel was layered as shown in figure 1 and was fed vertically. Domestic wastewater from the sewer underneath the southern part of Hamburg, Germany, was used.

The reference HLR for the first set was 8 cm/d. As the further objective is to determine the clogging potential, the HLR for another set of microcosms was 12 cm/d. The incubation of every microcosm was undertaken for 3 weeks in prior to the beginning of the experiment, by feeding tap water in the first week and wastewater in the following weeks. After that, 5 g of native European earthworms, *E. Fetida*, which was corresponded to approximately 10-12 individuals, were added into one of the microcosms for each set. The other microcosm had been operated without earthworm. Every reactor was fed once a day at the same period, except on Sunday. The experiment was allowed to run for 10 days. Sampling was carried out every 3 days. Analyses were performed

according to Standard Methods for the Examination of Water and Wastewater (Clescerl et al., 1999). The survival rate of earthworms was evaluated at the end of the experiment by hand counting the number as well as by weighting. Clogging potential was studied in both experiments by simply observing whether the flow rate into the reactor was reduced after each feeding. It could be stated that clogging occurred when the flow of wastewater into the microcosms appeared to be slower.

Results

For the experiment in Thailand, the ambient temperature during the experiment was around 26 °C at night and 28 °C during day time. According to the observation, the inflow through the reactors without earthworms was notably slower at day 5, especially in the reactor receiving swine wastewater with dilution factor of 1:1 and 1:2. For the one in Germany with domestic wastewater, every microcosm showed no sign of clogging. In terms of the swine wastewater quality, only analytical results at the end of the trial were presented here due to the inconsistency from the results at the beginning of the run. This was due to the fact that the microbial communities might not yet fully developed in the biosystem. The treatment efficiency of swine wastewater is shown in table 1. There was some reduction of organic matter in the experiment, which was reflected in approximately more than 50% of COD reduction for 1:1 dilution and 30% for the dilution factor 1:2. Low level of treatment was seen from the dilution 1:4. For the experiment in Germany, the results from the analyses were more consistent and average performance data could be made (table 2).

Moreover, data concerning the survival rate of earthworms from both experiments are shown in table 3. It is demonstrated that earthworms could thrive within the bed receiving swine wastewater, exhibiting the survival rate higher than 85%. There was no layer of accumulated sludge on the surface of every microcosm. For the case of domestic wastewater, the survival rate of earthworms based on the mass was found to be 52% for microcosm 3 (2.75 g) and 53% for microcosm 4 (2.65 g).

Discussion

Without the presence of earthworms, there was some clogging in the reactors receiving high-strength swine wastewater, whereas this was not the case in the microcosms with earthworms. As a result, it could be implied that earthworms could consume organic matter within the wetland body and this resulted in the non-clogged circumstance for the microcosms with earthworms.

According to the results presented in table 1, the microcosm with earthworms exhibited a better performance comparing to the one without them only in the case of the dilution 1:2, whereas the efficiency was similar in the other cases. In terms of nitrate and ammonia-nitrogen reduction, it was clearly seen that the influent (the wastewater before entering the treatment system) values of both parameters were very low. Nonetheless, focusing on the effluent (the wastewater after being treated) quality there exhibited the consistent trend that the microcosms with earthworms showed a better efficiency in reducing nitrogen. All the solid values from the table indicated that the reduction of solid occurred in every microcosm. It is remarked that the ones with earthworms exhibited better solid reduction comparing to the units without earthworms for each set of dilution, ranging from 6% better efficiency in the non-diluted samples to 18% in the dilution 1:4.

In general, low treatment performance from this experiment was probably due to several reasons. First, the height of the reactor was very short. Moreover, there was no inoculation phase to let the microbial communities within the cells became fully developed, including the missing of plantation. Lastly, the gravel size used in this experiment was larger than the size normally applied in constructed wetland due to limitation in sieving equipment.

Further, considering the treatment performance in Germany with domestic wastewater from table 2, few removal processes occurred in every microcosm with respect to most of the parameters. This could be attributed

Table 1 Average value from the experiment with swine wastewater

Value	Dilution 1:1			Dilution 1:2			Dilution 1:4		
	Inf.	Eff. 1	Eff. 2	Inf.	Eff. 1	Eff. 2	Inf.	Eff. 1	Eff. 2
COD (mg/L)	1308	692.3	692.3	846.1	500	615.4	576.9	538.4	538.4
TS (mg/L)	29300	19500	21400	19200	17800	18700	15700	10900	13700
TDS (mg/L)	6700	2000	3200	5500	2500	3700	2100	300	900
NO_3-N (mg/L)	5.5	2.9	3.7	4.1	1.77	2.4	2.1	0.88	1.9
NH_4-N (mg/L)	4	1.3	2.6	1.8	1.3	2.3	1.6	0.2	1.3
pH	7.13	7.1	7.1	6.84	7.05	7.03	6.82	6.87	6.58

Note; Inf.: Influent; Eff. 1: Effluent from microcosm with earthworms; Eff. 2: Effluent from microcosm without earthworm; mg/L: milligram per liter; COD: Chemical Oxygen Demand; TS: Total Solid; TDS: Total Dissolved Solid; NO_3-N: Nitrate Nitrogen; NH_4-N: Ammonium Nitrogen

Table 2 Average value from the experiment with domestic wastewater (w/o: without; w: with) at each HLR (in cm/d)

Value	Influent	Effluent w/o worms HLR: 8	Effluent w worms HLR: 8	Effluent w/o worms HLR: 12	Effluent w worms HLR: 12
BOD_5 (mg/L)	398.33	294.33	326	307	338
SS (mg/L)	187.25	178.50	189.5	204.25	176.25
TN (mg/L)	75.45	63.83	72.38	65.25	80.60
NO_3-N (mg/L)	0.76	1.22	1.46	0.71	1.11
NH_4-N (mg/L)	56.38	49.12	56.80	51.45	60.28
pH	7.18	7.46	7.50	7.41	7.40

Note; BOD_5: Biochemical Oxygen Demand; SS: Suspended Solid; TN: Total Nitrogen

Table 3 The number of earthworms survived in each configuration

Type of wastewater	Dilution factor	HLR (cm/d)	Number of alive earthworms before the experiment	Number of alive earthworms after the experiment
Swine	1:1	8	20	17
Swine	1:2	8	20	19
Swine	1:4	8	20	18
Domestic	1:1	8	11	5
Domestic	1:1	12	11	4

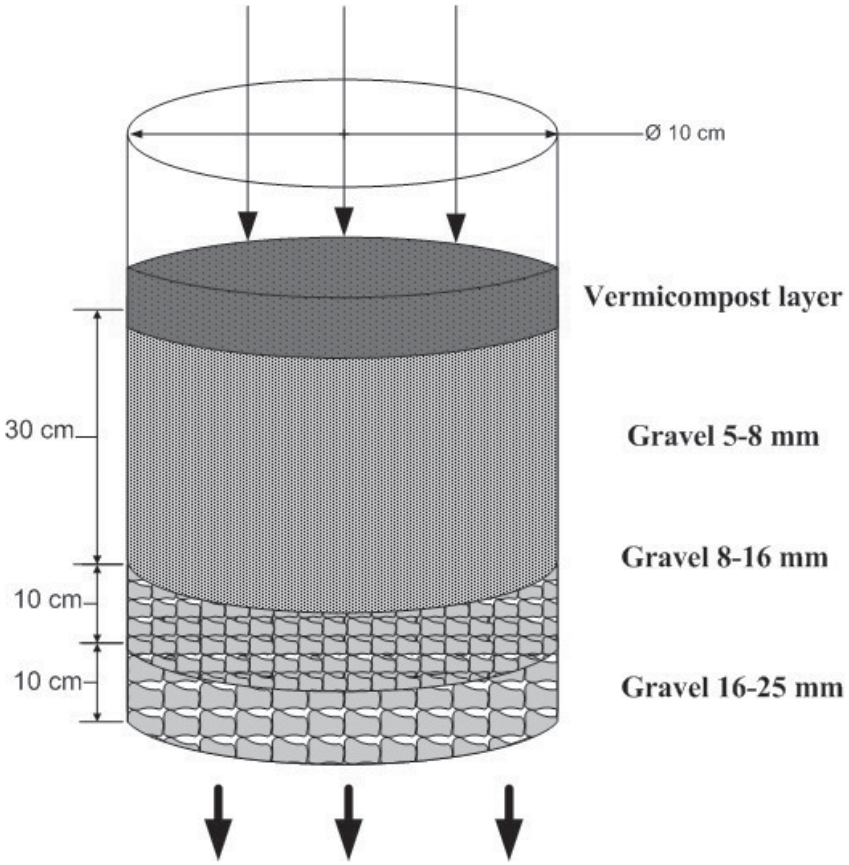

Figure 1 Schematic of the lab-scale earthworm-assisted constructed wetland receiving domestic wastewater

to the large gravel size and little development in biological community within the microcosms, so that the effective detention time was too low. In terms of the solid reduction, the set receiving HLR of 12 cm/d exhibited the results in compliance with the data from swine wastewater, in which the microcosms with earthworms exhibited better solid reduction. This was not the case for the set with 8 cm/d HLR where the microcosm without earthworms performed better. It might be because some of the earthwormsí cast was incidentally flushed out of the microcosm and presented in the effluent. In terms of nitrogen value, higher NH4-N content was observed in the microcosms with higher HLR. In contrast, the microcosms with higher HLR exhibited lower NO_3-N content. This could be because generally, higher feeding rate should allow lower amount of atmospheric oxygen, which is responsible for maintaining an aerobic condition in VSFCWs, into the microcosms, and hence leading to lower nitrification rate. It can also be seen that higher loading rate resulted in the lower treatment performance.

The results concerning earthworms survival rate shown in table 3 suggest that the organic within the wastewater provided them a very good source of food, which complies with the statement from other study stating that earthworms can consume organic waste and grow (Edwards, 2004). The reason behind a 50% survival rate shown from the experiment with domestic wastewater could be due to the number of earthworms put in the microcosms, which is far greater than the quantity of food available. This resulted in a competition for food among them. As one study concerning the vermicomposting of dry sludge predicted that 200 mg of organic was consumed by 1 g of earthworms per day (Prince et al., 1981). Therefore, the number of earthworms within the microcosms was undergone self-adjustment, and reflected to this final earthworm biomass. This reason

also explained why the survival rate of earthworms in swine wastewater is higher than in domestic wastewater. Comparing that study to this experiment, the average BOD value of 400 mg/L implied that 1 g of earthworms could consume approximately 150 mg of organic, which is apparently lower than the wastewater sludge vermicomposting. It can also be seen that, for higher HLR, each individual of earthworms gained more weight despite of the decrease in number.

Conclusion

The results preliminarily indicated that earthworms could thrive in both types of wastewater and help reducing clogging potential. They could live within the bed under the tropical ambient temperature of up to 28 ^{o}C. Applying maximal recommended value of HLR for domestic wastewater to the bed receiving swine wastewater could lead to clogging of the bed unless the wastewater is diluted or the earthworms are applied. This technique could be considered as a promising solution with the high strength swine wastewater, as it could reduce any clogging potential within the bed. In terms of wastewater quality, more research is needed albeit the preliminary data showing a sign of treatment from both microcosms (with and without earthworms). Based on the data obtained from this experiment, scale-up to pilot-scale, with the conventional depth of constructed wetland and planting, is highly recommended to confirm the results and find the optimized operating condition for this technology.

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