VETIVER LANDFILL LEACHATE PERFORMANCE UNDER IRRIGATION

KHẢ NĂNG XỬ LÝ NƯỚC RỈ RÁC CỦA CỎ VETIVER BẰNG PHƯƠNG PHÁP TƯỚI

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Abstract - Landfill leachate in Vietnam differs from that produced in developed countries by its extremely high content of organic, heavy metals, and nutrients. In this study, vetiver grass (*Chrysopogon zizanioides* L.) is applied to treat landfill leachate. The grass is firstly irrigated by domestic wastewater for acclimatization, then by diluted landfill leachate with the quantity of 1L/d. Various dilution factors (leachate:domestic wastewater) of 1:5, 1:3, 1:2, 1:1, and original leachate are tested in turn. Different irrigation frequencies are applied for a dilution: twice a day and three times a day. The toxic threshold is firstly recorded at dilution factor of 1:1, where the vetiver grass shows limited growing. After 70 days more, the grass grows well when irrigated with leachate (no dilution). Best performance is recorded with a dilution factor of 1:2 and irrigation frequency of three times a day. The quality conforms to National Technical Regulation on Wastewater of the Solid Waste Landfill Sites in terms of BOD, N, P and heavy metals. The outcomes strongly present possible treatment of landfill leachate with vetiver by irrigation.

Key words - Vetiver; landfill leachate; wastewater; treatment; irrigation

Tóm tắt - Nước rỉ rác ở Việt Nam có đặc thù nồng độ chất hữu cơ, kim loại nặng, và dinh dưỡng cao. Trong nghiên cứu này, cỏ vetiver (*Chrysopogon zizanioides* L.) được áp dụng để xử lý nước rỉ rác. Ban đầu, cỏ được tưới bởi nước thải sinh hoạt cho thích ứng, rồi bởi nước rỉ rác pha loãng, khối lượng tưới là 1L/d. Nước rỉ rác pha loãng bằng nước thải theo các tỷ lệ 1:5, 1:3, 1:2, 1:1, và không pha loãng lần lượt được thử nghiệm với hai chế độ tưới: 2 và 3 lần một ngày. Ngưỡng chịu đựng, đầu tiên được ghi nhận ở tỷ lệ 1:1, biểu hiện bằng tốc độ tăng trưởng chậm. Sau hơn 70 ngày, cỏ được tưới bằng nước rỉ rác nhưng vẫn phát triển bình thường. Hiệu quả xử lý tốt nhất được ghi nhận với tỷ lệ pha loãng 1:2, tần suất tưới 3 lần một ngày. Hàm lượng chất hữu cơ, N, P, và kim loại nặng đạt quy định xả thải. Kết quả cho thấy khả năng ứng dụng của cỏ vetiver trong xử lý nước rỉ rác bằng phương pháp tưới.

Từ khóa - Vetiver; nước rỉ rác; nước thải; xử lý; phương pháp tưới.

1. Introduction

Vetiver grass (*Chrysopogon zizanioides* L.) has been used for soil and water contamination as a phytoremediation [1]. Due to its tolerance of numerous contaminants such as organics, heavy metals, nutrients, vetiver grass has been applied to various wastewater treatment [1-3]. By its application, vetiver offers environmentally friendly, saving energy, and low investment wastewater treatment systems.

Landfill leachate in Vietnam differs from that in developed countries due to its considerably high organics, heavy metals, and nutrients contents. A number of treatment technologies have been applied. Most of them use both biological and physico-chemical processes. Large amount of equipment and a lot of chemicals used in these technologies result in considerably high costs of investment and operation (2.7-4.0 USD/m^3).

This study aims to use vetiver as phytoremediation in landfill leachate treatment. The biggest purpose of this research is to elucidate applicability of vetiver grass in leachate treatment by irrigation method. Adaptability of vetiver to leachate was studied in order to find out a toxic threshold, caused by high contents of organic matters, nutrient, and heavy metals, where vetiver shows limited growth.

2. Materials and methods

2.1. Feeding leachate

Feeding wastewater is prepared from landfill leachate diluted by domestic wastewater with different ratios of 1:5, 1:3, 1:2, 1:1, and no dilution (only leachate). The leachate was taken every two days from collection channel of leachate treatment system of Khanh Son landfill, Danang City, Vietnam. Quality of leachate is shown in Table 1. Khanh Son is an old landfill with more than 10 years in operation. As a result, its leachate contains hardly biodegradable compounds, which normally is degraded by FENTON process. Ratio BOD/COD = 0.62-0.64 is suitable for biological treatment. pH is neutral so that no adjustment is needed. The experiments took place from March to September 2016.

Table 1. *Quality of Khanh Son landfill leachate*

No.	Parameter	Unit	Value
1	Temperature	^oC	27.6-28.2
2	pH	-	6.8-7.3
3	BOD	mg/L	4,130-4,320
4	COD	mg/L	6,590-6,680
5	TN	mg/L	331-342
6	TP	mg/L	28.2-29.1
7	Pb	mg/L	0.14-0.45
8	Zn	mg/L	0.72-0.84
9	Fe	mg/L	125-144
10	Hg	mg/L	0.31-0.57

Domestic wastewater is taken from sewerage of Danang College of Technology (DCT), The University of Danang. It is produced mostly from the septic tank and hand washing. Quality of domestic wastewater is not analysed during the experiment. Quality of the domestic wastewater is presented in Table 2.

Table 2. *Quality of DCT domestic wastewater*

No.	Parameter	Unit	Value
1	Temperature	^oC	26-37
2	pH	-	6.6-7.3
3	BOD	mg/L	100-120
4	COD	mg/L	180-210
5	TN	mg/L	17-23
6	TP	mg/L	3.2-4.9
7	NH_4^+	mg/L	10-13

2.2. Experimental set up

Three plastic pots are set for this experiment for obtaining standard deviations. Size of each pot is DxH = 450x800 mm (D-Diameter, H-Height). One vetiver clump is grown in each pot. The pots are successively filled from bottom to the top by 600 m of crushed stone (10-20 mm) and 100 mm of soil. On the surface of soil, a Ø21 mm uPVC pipe is stuck 45^o for irrigation. Down end of the irrigation pipe is directed to vetiver root. For each pot, a Ø21 tap is installed at the bottom for collecting treated wastewater sample (Figure 1).

Bore water and wastewater, from feeding wastewater tank, is delivered to vetiver root by three dosing pumps (ETATRON DLX 8-10, Italia) through irrigation pipes. The pumps flowrates are set at 50 mL/min. A timer is installed to control operational regimes of three pumps.

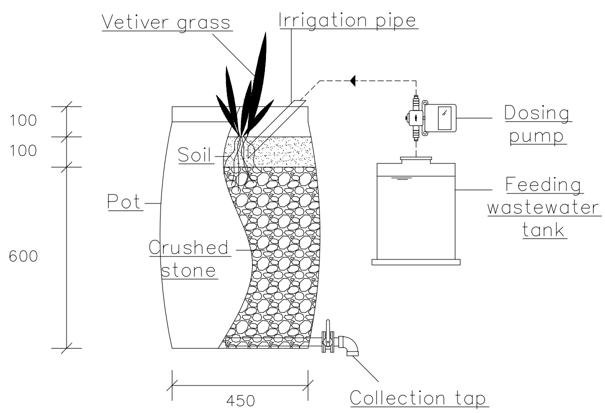


Figure 1. *Experimental set up for vetiver irrigation*

2.3. Acclimatization and steady state

During acclimatization period, each clump is watered with only bore water for 2 weeks, 1 L/d, twice a day. Afterward, only domestic wastewater is applied for 2 weeks, 1 L/d, twice a day. For supplemental beneficial microbes, a volume of 1 mL of EM is added to each irrigation. The EM has been made and tested for growth support with vetiver and different herbs by author and colleagues in Division for Environmental Engineering, DCT. The results from EM test are not presented in this article.

After the acclimatization period, vetiver is irrigated with leachate, which is successively diluted by domestic wastewater with ratios 1:5, 1:3, 1:2, 1:1, and no dilution (only leachate). For each dilution, each vetiver clump at which COD removal is highest, is expectedly obtained. Two irrigation strategies are applied with optimal ratio: twice (at 06:00 and 18:00) and three times (at 00:00, 08:00, and 16:00) a day.

Experimental works are summarized in Table 3. In experiments E15, E13, E12, and E11, irrigation frequency is once a day.

Acclimatization lasted from March to April 2016. Experiments E15, E13, E12, E11, and E12-2 lasted from April to July 2016. Experiment E12-3 took place from July to September 2016 (2 week for getting sample; the next 4 weeks for vetiver getting ready with original leachate). Experiment E10 lasted from September to October 2016.

Table 3. *Summary of experimental work*

No.	Experiment	Description	Duration
1	E15	Irrigation with leachate + domestic wastewater at ratio 1:5	2 weeks
2	E13	Irrigation with leachate + domestic wastewater at ratio 1:3	2 weeks
3	E12	Irrigation with leachate + domestic wastewater at ratio 1:2	2 weeks
4	E11	Irrigation with leachate + domestic wastewater at ratio 1:1	2 weeks
5	E12-2 (optimal dilution)	Irrigation with leachate + domestic wastewater at ratio 1:2. Irrigation frequency is twice a day	2 weeks
6	E12-3 (optimal dilution)	Irrigation with leachate + domestic wastewater at ratio 1:2. Irrigation frequency is three times a day	6 weeks
7	E10	Irrigation with only leachate. Irrigation frequency is three times a day	2 weeks

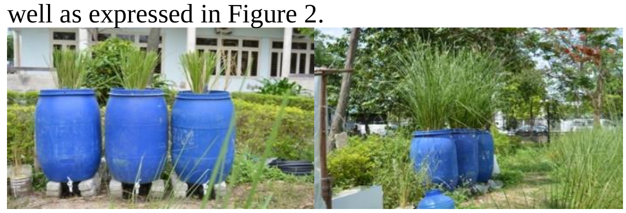
2.4. Sampling and analysis

For each dilution and irrigation frequency, samples are taken after two weeks feeding. The obtained samples are qualified by parameters pH, COD, BOD, TN, TP, NH_4^+, Pb, Zn, Fe, and Hg. The protocols for analysis of these parameters are referred to [4]. The quantification of microbial communities in effluent is carried out by standard plate count method so that the protocols can be found in [5]. Analysis data from three samples, taken from three pots, can produce standard deviation.

3. Results and discussions

3.1. Removal performance

During the acclimatization period, the vetiver grows well as expressed in Figure 2.



(a) *(b)*

Figure 2. *Growth of vetiver during acclimatization*
(a) At the beginning; (b) After 4 weeks acclimatization.

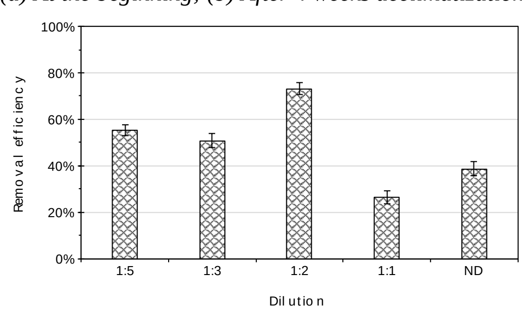


Figure 3. *COD removals under experiments (ND-No Dilution)*

COD removals are described in Figure 3. Removal efficiencies are 55.7, 50.8, 73.3, 26.1, 38.2% obtained with experiments E15, E13, E12, E11, and E10, respectively. High dilution experiments (E15 and E13) present similar

COD removal efficiencies. At E11 and E10, COD removal efficiencies are lower than those obtained with E15 and E13. Highest COD removal efficiency is obtained with E12. COD in E12 is decreased from 2213 (feeding wastewater) down to 590 mg/L (effluent). Lowest effluent COD is obtained with value of 490 mg/L in E15.

High COD removal of 99.1% by vetiver is reported in an experiment, in which leachate is treated by vetiver grass [6]. In the experiment, leachate contains extremely high content of COD and BOD (50,000±2,400 and 27,000±1,700 mg/L, respectively). Such a high COD removal efficiency contributes to slow irrigation rate of 0.2 mL/min.

Nutrient removal efficiency also presents similar tendency. Highest TN and TP removal efficiencies are recorded in E12 with values of 62.3 and 77.1%, respectively. Lower removal efficiencies are observed in the rest experiments: In E15, TN and TP removal efficiencies are 43.8 and 57.4%; In E13, the removal efficiencies are 47.1 and 62.2%; In E11, the efficiencies are 40.6 and 41.6%; In E10, those values are 40.1 and 49.8%, respectively (Figure 4). TN and TP content in E12 decreases from 114 and 96 (feeding wastewater) to 43 and 22 mg/L (effluent), respectively. Lowest effluent TN and TP are obtained with the values of 31 and 2 mg/L, respectively, in E15.

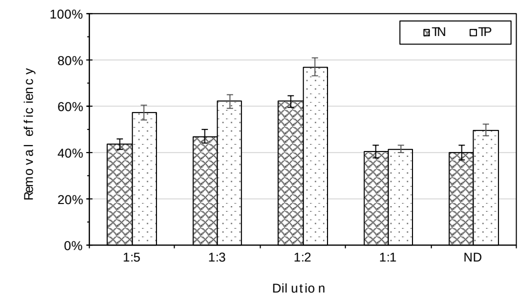


Figure 4. *Nutrient removals under experiment E12-2*

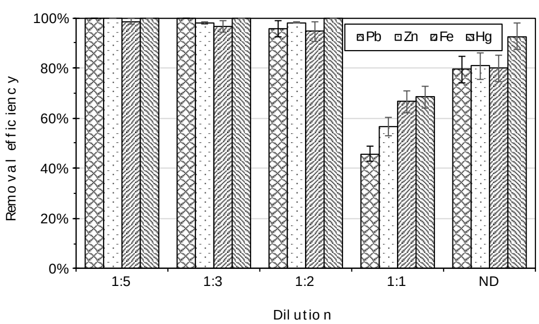


Figure 5. *Heavy metals removals under experiment E12-2*

For heavy metals removals, outcomes from experiments E15, E13, E12 show similar efficiencies. In these tests, heavy metals are almost not detected in the effluent. In E11, Pb, Zn, Fe, and Hg show lower removal efficiencies with values of 45, 56.4, 66.7, 68.4%, respectively. In E10, removals efficiencies are higher with values of 79.4, 80.4, 79.6, and 92.7% for Pb, Zn, Fe, and Hg, respectively (Figure 5).

pH of effluent (5.7-6.1) in the experiments drops slightly compared to those of feeding wastewaters. At this pH, most heavy metals exist under the soluble form. Consequently, most of the heavy metals are absorbed into vetiver biomass.

Experiments E12-2 and E12-3 are carried out to examine removal performance under the higher frequency of irrigation. COD and nutrient removals under experiments E12-2 and E12-3 are compared in Table 4. COD, TN, and TP removals efficiencies are improved under E12-3 compared to E12-2. The improvement is attributed to longer hydraulic retention time. Higher COD removal efficiency under lower flowrate has been reported in a research of [6]. Various irrigation flowrates of 0.2, 0.6, and 1.0 mL/min are applied. COD removal efficiencies decreases under higher flowrate with values of 96.0, 87.4, and 81.7%, respectively.

Table 4. *Removal performance under different irrigation regimes*

Experiment	Removal efficiency, %		
	COD	TN	TP
E12-2	75.6 ± 2.3	62.3 ± 2.2	77.1 ± 3.5
E12-3	83.7 ± 2.8	70.1 ± 2.5	86.0 ± 3.6

After experiment E12-3, the outcome from E10 presents a growth of vetiver under original leachate irrigation. Removal performance of vetiver in E10 also improves compared to that in E11. This improvement is attributed to adaptation of vetiver to pollutants in leachate through the experiments and, especially, 6 weeks of E12-3. Variation of COD, TN, and TP removal efficiencies are described in Figure 6.

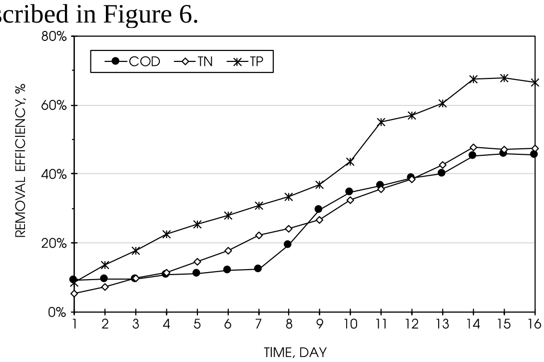


Figure 6. *Removal performance under experiment E10*

A similar model has been applied for Stotts Creek Landfill, Tweed Shire, Northern Rivers region, New South Wales, Australia. The landfill receives wastes from both Tweed Heads and Murwillumbah townships and neighbouring local government areas. The leachate is treated by irrigation on vetiver wetland [7]. In this design, 6 ha of vetiver planting would use up to 1.68 ML/d, without any surface runoff or deep drainage. However, humidity in New South Wales, Australia, is remarkably lower than that in Vietnam. Leachate uptake capacity of vetiver therefore is higher in Australia than that in Vietnam.

3.2. Microbial aspect

In the first week of E10, COD removal efficiency develops slightly from 9.3 to 12.5%. Afterwards, a rapid increase in COD removal is observed from 19.5 to 45.4%. On the other hand, nutrient removal efficiencies increase almost linearly at the beginning throughout the experiment. After two weeks, removal performance reaches steady state. COD removal efficiency value is 45.3, 45.7, 45.4% at day 14, 15, and 16, respectively. TN removal efficiency value is 47.7, 47.1, 47.6% at day 14, 15, and 16, respectively. TP removal efficiency value is 67.4, 67.7, 66.5% at day 14, 15, and 16, respectively.

The microbial investigation is carried out in order to elucidate removal performance and vetiver growth-promoting. *Azospirillum*, *Azotobacter*, *Bacillus*, *Pseudomonas*, *Zoogloea*, *Nitrosomonas*, and *Nitrobacter* genera are objects for examination.

Zoogloea genus population remains similar during first week of E10 in range of 1.1-2.4 x 10^5 CFU/100 mL. In this period of time, *Pseudomonas* genus also presents similar tendency of the population in the range of 4.4-5.3 x 10^7 CFU/100 mL. Afterwards, Zoogloea population develops stronger from 3.7 to 8.0 x 10^5 CFU/100 mL and keeps stable from the 14^{th} day with values of 8.3-8.5 x 10^5 CFU/100 mL. *Pseudomonas* population grows more quickly from 6.0 to 11.0 x 10^7 CFU/100 mL and reaches steady state at the 13^{th} day with values of 10.8-11.5 x 10^7 CFU/100 mL. These two genera take responsibility for hard biodegradation organic matters [8]. It can explain for the slow development of COD removal efficiency in the first week and rapid improvement in the following days of the experiment. Stable COD removal performance also results from the steady state of these two bacterial genera.

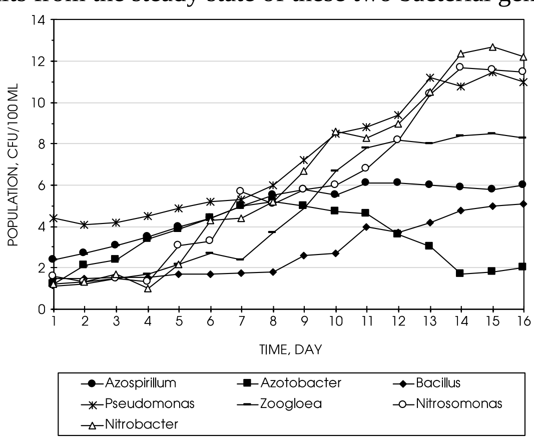


Figure 7. *Microbial population under experiment E10 Azospirillum: x10^4; Azotobacter: x10^4; Bacillus: x10^4; Pseudomonas: x10^7; Zoogloea: x10^5; Nitrosomonas: x10^5; Nitrobacter: x10^5 CFU/100mL*

Azospirillum, *Azotobacter* genera grow in population at the beginning of experiment E10. Steady state is obtained from day 10^{th}. Similar to those of *Zoogloea* and *Pseudomonas*, slow growths of *Nitrosomonas* and *Nitrobacter* population are also observed. *Azotobacter*, *Nitrosomonas*, and *Nitrobacter* genera are responsible for nitrogen removal [8]. Furthermore, *Azospirillum* genus undertakes phosphate solubilizing [8, 9]. For these reasons, development in the population of these four genera results in a linear increase of nutrient removal efficiency from the beginning to the 14t day of E10. *Bacillus* genus consumes biodegradable organic matters for carbon and energy sources [9]. Presence of this genus proves that toxic matters (aromatic compounds and heavy metals) in original leachate is not able to create sufficient stressful conditions. For this reason, *Bacillus* does not form a spore.

4. Conclusions

Several conclusions are withdrawn from the outcomes of this experiment:

- Optimal treatment of leachate is obtained as it is diluted by domestic wastewater with the ratio of 1:2. COD removal efficiency of 73.3% is recorded. Removal efficiencies of TN and TP are 62.3 and 77.1%, respectively. Nonetheless, effluent COD value remains over the level prescribed in Technical National Regulation for discharge (590 versus 300 mg/L). TN of effluent meets Technical National Regulation for discharge (43 versus 60 mg/L);

- Irrigation of three times per day results in greater removal efficiencies than that obtained under irrigation of twice a day;

- Vetiver is able to grow under irrigation with original leachate from Khanh Son landfill. Nonetheless, the grass needs a long period of time for acclimatization by gradually increasing pollutant concentrations in leachate;

- Under irrigation with original leachate, N and P are removed more easily and quickly than hard-biodegradation organic matters;

- Vetiver grass (*Chrysopogon zizanioides* L.) presents high potential for landfill leachate treatment by irrigation, a low-cost method, without polluting aquifers;

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