Nitrogen transformations in different layers of vertical flow constructed wetland (VFCW) treating faecal sludge.

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Introduction
In urban areas of developing countries, thousands of tons of faecal sludge (FS) collected daily from on-site sanitation installations are disposed of inappropriately. In Thailand, only 42% of the municipalities avail of FS treatment systems but unfortunately only half of the existing facilities are well functioning, while the rests are out of order [1]. FS typically contains high concentrations of pathogens and may also be contaminated by hazardous pollutants [2,3]. It has high concentration of nutrients, especially nitrogen (N) and phosphorus. Nitrogen is one of the major priority pollutants in FS, in the form of ammonia (NH$_4^+$) which causes significant depletion of oxygen and causes toxicity to aquatic life. Initial studies followed by several others have identified the constructed wetlands as a proven, low-energy process to substantially reduce nutrient levels, including N, in wastewater. Results from the wetland treatment systems have been recently documented with the focus on nutrient removals [4].

Methodology
This study focuses the effects of different filter media on N transformations in the vertical flow constructed wetland (VFCW) treating FS. The VFCW unit was made of square plastic tank and planted with cattails (Typha augustifolia), consisting large gravel at the bottom, small gravel at the middle and fine sand on the top. A PVC pipe with small holes was connected in the middle of the VFCW system in which each is stalled with a sensor at 3 different levels to continuously monitor pH, dissolved oxygen (DO) and oxidation reduction potential (ORP) values. FS samples were collected from a nearby municipality, containing pH 7.0 ± 2.7, temperature 30 ºC, COD 29.6 ± 2.4 mg/L and TN 810 ± 150 mg/L. The VFCW unit were applied once a week with FS at a solid loading rate (SLR) of 250 kg TS/m$^2$.year.

Results
1. N mass flow in sand layer
Figure 1a indicates that VFCW unit could achieve about 32% NH$_4^+$-N mass deduction over the retaining period in sand layer (1.5 days). After feeding about 1 day, NOx-N mass has been increased until a maximum of 5.4 g N/m$^2$ is reached and later slightly decreased to 5.29 g N/m$^2$. Org-N mass continuously decreased from 192 to 62 g N/m$^2$, which is about 68% removals after feeding for 1.5 days. TN mass suddenly decreased after operation of 6 hrs which is about 35% removals. An addition 18% of TN constantly decreased over infiltration period (1.5 days). The results correlate well with pervious study by Panuvatvanich (2010) [5] that nitrification-denitrification reaction could mainly occur in a sand layer of VFCW unit. In addition Figure 1b shows that a slight decrease in DO mass decreased did not well correspond with the increase in NO$_x$ in a sand layer. This is possibly due to the DO in this part would come from dissolved oxygen in percolate. Sun et al (2014) [6] reported that oxygen can be transferred into and consumed inside a constructed wetland via several main routes such i) direct transferred from the air, ii) transfer from plant roots, iii) dissolved oxygen in biofilms and dissolved oxygen in percolate.
2. N mass flows in small gravel layer
Figure 1c reveals that all of N species tend to reduce in this small gravel layer. NH$_4$-N mass decreased constantly about 30% whereas NO$_3$-N decreased about 70% in this layer. Org-N removal of about 25% were obtained over 4.5 days. The results illustrated that NH$_4$-N could be converted through nitrification reaction to be NO$_3$-N after which the denitrification process would occur as apparently indicated by DO concentrations, pH and temperature in this layer.

3. N mass flows in large gravel layer
Further to those processes in a small gravel layer, NH$_4$-N, NO$_3$-N and Org-N masses continued decreasing about 25%, 77% and 10%, respectively, in a large gravel layer. TN mass of about 37% was constantly decreased after 4.5 days of percolate impounding. The results reaffirm that the nitrification/denitrification process would likely occur in a gravel layer in which conversion of NH$_4$-N to NO$_2$-N and NO$_3$-N and then converted NO$_3$-N into N$_2$ are apparent [5].

![Figure 1](image1.png)

**Figure 1.** (a) N mass flow in sand layer of VFCW units, (b) Relationship of NO$_x$ and DO mass variation in sand layer, N mass flow in (c) small gravel layer and (d) large gravel layer of VFCW units

**Conclusions**

In a sand layer of VFCW units, about 32% of NH$_4$-N was mainly transformed by nitrification reaction to NO$_2$-N under aerobic condition (DO concentration about 4.35 mg/L and ORP about 167 mV), resulting in TN mass of 53% be removed. At the slightly lower DO concentration and ORP about -97 to 115 mV in a gravel layer, it was likely that the nitrification process could continue at the first step causing about 25% of NH$_4$-N be transformed and about 77% of NO$_3$-N mass continuously decreased under anaerobic condition (ORP about -289 to -462 mV). The results could reaffirm that the denitrification process is the main process for TN removal in gravel layer.

To maximize N removal in a VFCW treating FS, it would suggest that VFCW unit with a greater sand layer depth could create favourable conditions for nitrification reaction and prolonging the impounding time in a gravel layer would enable the denitrification reactions.
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References


**Sludge Treatment Wetland as Post-Treatment of Toilet-Linked Biogas Plant: A Cost-Effective & Technically Feasible Solution in Tropical Countries**

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**Keywords:** Sludge Treatment Wetland; Toilet-Linked Biogas Plant; Phragmites karka; Napier Bajra

**Abstract**

**Introduction**

Over the past twenty years government and private institutions in India have been promoting the use of Toilet-Linked Biogas Plants (TLBP) as one option to solve the problem of access to sanitation, especially in rural areas. As many rural households have access to a biogas system, connecting the toilets to them may provide a solid technical solution for the human waste. The digested sludge (so-called slurry) is popular for use in agriculture as a soil conditioner. However, little is known about its properties. Previous studies recommended slurry post-treatment prior to use due to the high pathogen concentration. Sludge Treatment Wetland (STW), an emerging solution for faecal sludge treatment, could be a feasible technology to treat the slurry. Research studies conducted in countries with a tropical climate like Cameroon and Thailand suggest that STW could be used to treat faecal sludge collected from pit latrines, septic tanks and other on-site sanitation systems (Kengne et al., 2011; Koottatep et al., 2004), however STW has not been applied as TLBP’s effluent post-treatment.

In this study, eight pilot-scale experimental units had been implemented in Gujarat India to evaluate the STW’s removal efficiency and their by-products quality. Based on the research results, this paper recommends practical design and operation parameters such as: sludge loading rate, plant species and harvesting period, land requirement, bed configuration and sludge accumulation, in order to implement the STW at household-size level.

**Methodology**

To evaluate the STW performance on sanitisation of slurry from TLBP’s, first the slurry were characterised during seven sampling campaigns and second, eight pilot-scale experimental units were constructed and operated outdoors at Pathri Village located in Valsad district of Gujarat, India (20°50’27”N, 72°59’56”E). The slurry was collected at the outlet of a household-size TLBP and its physical properties, organic matter content, nutrients concentration and pathogen indicators were analysed in a local certified laboratory. The experimental units were constructed and operated at four sludge loading rates (40.5, 81.0, 121.5 and 162.0 kgTSS/m²-year) in semi-batch loading cycles (feeding period of 7 days in daily equal portions, followed by a resting period of one week) during three months starting early December 2013; each unit was a plastic cylindrical tank with 0.70 m height and 0.75 m diameter. As a result of sludge treatment, three by-products were generated and evaluated from a reuse in agriculture point of view: i) the biosolids accumulated at STW’s top layer, ii)
the water leachate collected at bottom layer and iii) the biomass production comparing two native plant species: *Phragmites karka* and *Napier Bajra* hybrid grass. See Figure 1.1.

**Results**
The results of slurry characterisation, indicates high concentrations of: organic matter (VSS: 68.7%TSS, COD: 93.08g/L), nutrients (in mg/kg: NO$_3$-N: 128.3, NO$_2$-N: 0.47, NH$_3$-N: 966, P$_2$O$_5$: 1,203 and K: 1,005) and pathogen indicators (*E.Coli* $2.62*10^5$ CFU/g dry-weight basis).

The STWs by-products results indicate the following: i) the biosolids at 4 STW configurations showed similar efficiencies in terms of nutrients concentration, mineralisation and hygienisation, but concerning sludge dryness, significant differences were observed at different loading rates (from an influent moisture content ranging between 96.7-98.3% to a final product moisture of 19.5%, 27.3%, 38.9% and 49.0% at 40.5, 81.0, 121.5 and 162.0 kgTSS/m$^2$/year, respectively); ii) the leachate quality of 4 STW configurations complied with the standard Indian limits for reuse in agriculture and could be classified as Class E for USEPA water reuse guidelines; iii) both plant species were well adapted and there were no significant differences in the STW performances; however, *Phragmites karka* biomass production (measured in terms of relative growth rate) was almost two times higher than *Napier Bajra* hybrid grass.

![Figure 1 TLBP, STW and its by-products](image)

**Conclusions**
The TLBP combined with STW can be a good on-site sanitation solution, applicable especially in rural areas of tropical countries. If a STW is implemented as a post-treatment of TLBP’s effluent, not only improves the slurry quality but also enables potential reuse of the treated water as an irrigation source. Additionally, the plants used in STWs (*Phragmites karka* and *Napier Bajra* hybrid grass) might be a good source of forage. These by-products have an economic value, enhancing the STW advantages of being low cost in operation and maintenance. This makes the technology of TLBP combined with STW an applicable sanitation solution for countries with a tropical climate.

**Preliminary recommendations**

- **sludge loading rate**: a loading rate of 100 kg TSS/m$^2$-year is recommended to obtain a final product (biosolid) with appropriate moisture content;
• **plant species**: the use of *Phragmites karka* is highly recommended, with a monthly harvesting period;
• **land requirement**: a household-size TLBP for a family of five adult members and 2-4 cows requires approximately 9 m²; and
• **bed configuration**: three layers, large gravel, medium gravel and coarse sand with a height between 10-15 cm.

Since most of the STWs were applied successfully in Europe as post-treatment of primary and secondary sludge, the recommended sludge loading rate are between 22 and 65 kg TSS/m²-year (Nielsen, 2007, Uggetti et al., 2010, Troesch et al., 2009), however in the present study a high sludge loading rate is recommended (100 kg TSS/m²-year) due to local weather conditions (tropical climate) and local plant’s characteristics.

**References**


**Faecal sludge treatment: Reducing footprint with conditioning**

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Keywords: Drying beds; Resource recovery; Renewable Energy.

**Introduction**

An estimated 6,000 m³ of faecal sludge (FS) is produced daily in onsite sanitation technologies of Dakar, Senegal. Vacuum trucks collect and transport approximately 1,500 m³ of FS to FS treatment plants. These plants treat FS by settling tanks followed by dryings beds and operate at design treatment capacity, meaning that daily approximately 4,500 m³
of FS is directly discharged into the urban environment (BMGF, 2011). Besides the impact on public and environment health, this lack of FS treatment capacity prevents resource recovery from FS treatment endproducts at scale. Industries in Sub-Saharan Africa are in need of alternative fuels to meet their energy requirements and dried FS has an energy potential comparable to other biofuels already in use by industries (Muspratt et al., 2014, Diener et al., 2014). Depending on the local market environment, revenues created from transforming FS into an industrial fuel could be significantly higher than if used in agriculture (Diener et al., 2014). However, FS treatment capacity needs to be increased for industrial-scale enduse to become a reality. As representative for urban areas throughout Sub-Saharan Africa, access to adequate space in Dakar for treatment of current and future FS quantities is difficult. This results in treatment plants often being located in the outskirts of a city, increasing costs of FS transport and sanitation services at the household level. Seck et al. (submitted) demonstrated that relatively simple treatment innovations such as daily turning of FS on the surface of drying beds can reduce their footprint by around 20%. No information was found in the literature on the use of conditioners with FS. This research was conducted at the Cambéréne Faecal Sludge Treatment Plant (FSTP) in Dakar, Senegal, to assess the technical and financial viability of using conditioners to enhance solid-liquid separation of FS, to ultimately reduce the required footprint for treatment with settling tanks and drying beds.

**Material and Methods**

Five synthetic (CP313, CP314 and CP317 from Flonex Switzerland; 8651 and C2064 from Ensola Switzerland) and three natural conditioners (chitosan 0.5vol%, *Moringa Oleifera* seeds 5wt%, lime) were evaluated based on consultation with manufacturers and their usage for conditioning sludge from water and wastewater treatment. The optimal dosage for settling was estimated based on the lowest concentration of total suspended solids (TSS) in the supernatant after settling in Imhoff cones. The optimal dosage for dewatering (e.g. on drying beds) was estimated based on Specific Resistance to Filtration\(^1\) (SRF). These analyses were done in triplicate to evaluate which conditioners performed best with FS. Four conditioners (CP314, C2064, lime and chitosan) were then evaluated for combined settling and drying with column tests, as illustrated in Figure 1, to estimate settling velocity and percolation rates. These results were compared to unconditioned FS as a control.

![Figure 1: Settling (left) and drying (right) columns to mimic settling tanks and drying beds.](image)

**Results and Discussion**

All conditioners used in this study enhanced FS settleability and dewaterability compared to unconditioned FS. However, doses for optimal settleability and dewaterability were not the same. Therefore, to select a dose that could improve both treatment processes, the dose was selected that performed best overall based on TSS concentrations in the supernatant, SRF and visual observations such as floc size and constitution.

\(^1\) Specific Resistance to Filtration (SRF) is a parameter to quantify the dewaterability of sludge by filtering it at a vacuum of 50 kPa through a Buchner Funnel, measuring filtrate volume over time. The method is described in detail in DIN EN 14701-2:2013.
Overall, chitosan and *Moringa oleifera* seeds performed best at concentrations of 1 ml/g total solids (TS) and 10 ml/g TS. Apart from CP313 which performed best at 7 ml/g TS, a dosage of 4 ml/g TS resulted in best settleability and dewaterability for all other synthetic conditioners. Lime performed best at a dosage of 1 g/g TS. Compared to unconditioned FS, these concentrations reduced TSS in the supernatant by 62 to 95% TS and the SRF by 80 to 90%. On average, the conditioned sludge settling rate was 12 cm/min, but could not be determined for unconditioned FS due to its poor settleability, indicating a significant increase in settling performance. Perculation of 90% of the leachate in the filter columns took 2 to 35 hours for conditioned FS, compared to 20 to 80 hours for unconditioned FS. Higher rates of settling and percolation can increase treatment performance and also reduce the required footprint. However, these benefits need to be balanced with the associated capital and operating costs. At Cambérène FSTP, conditioning would add annual treatment costs of 30 to 47% for synthetic conditioners, 14% for Chitosan and 355% for Lime. In this study, comparing these costs with increased treatment capacity or the reduced footprint was not feasible due to the scale. However, based on the increase in solid-liquid separation, local availability and affordability, Chitosan which can be produced from sea crustaceans had the greatest potential for financially viable application in Dakar.

**Conclusions**

Use of conditioners can significantly increase the performance of FSTP, thus, reducing their required footprint, increasing treatment capacity and opportunities for resource recovery from treatment endproducts. This is especially relevant for urban areas where space for treatment plants is limited. Further research is ongoing for the use of conditioners with less stabilized FS, such as from public toilets.

**References**


