Engineered Reed Bed Treatment System as a Low Cost Sanitation Option for the Philippines

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Introduction

Degradation of water quality in urban areas is mainly attributed to the indiscriminate disposal of domestic wastewater. More than 90% of the sewage generated all over the Philippines is not disposed or treated in an environmentally acceptable manner. Moreover, only one percent of the produced contaminated wastewater is being treated nationwide. This predicament is a constant threat to the local populace, the environment and an immense financial burden to the struggling economy.

The sanitation and sewerage sector in the Philippines, which so far may be considered as underdeveloped, is in great need of technology transfer and financing. Estimates show that the national sanitation coverage declined dramatically from 74.9% in 1991 to 69.4% in 1998[1]. Attempts to provide low-cost technologies for local government units were initiated as early as the 70's through clustered household and cheap collection systems that led to partial treatment through communal septic tanks. Solutions considered these days are mainly in the construction of conventional or centralised sewer treatment plants, with high cost for the construction of collection systems, operating and maintenance costs. These systems are feasible and can be justified only in highly populated cities, but neither in suburban nor rural areas. One possible approach to these areas is the construction of low cost sanitation facilities like an **engineered reed bed treatment system**, with low construction and maintenance costs. Although this innovative technique is accepted worldwide and proven efficient, such a solution is practically unknown in the Philippines until today.

The use of Natural Systems in the treatment of liquid wastes has been getting substantial attention in many environmental conferences and fora.[2] The use of plants, water and soil in a composite unit generally called a wetland has been applied in many areas and applications from domestic to industrial waste sources. Other terms which refer in part or in general to natural treatment systems include; Land Treatment, Phytoremediation, constructed wetland, etc. The realization of the importance of wetlands, which ecologists often refer to as "nature's kidneys" for their water cleansing capacity, has grown since the 1960s. The interest in this new and emerging field of Environmental Studies has led to a deeper understanding of the mechanisms and issues involved in its use. A significant and promising facet of this technology is the low energy requirement in its application.

Project Partners

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[1] UNDP Philippines Country Study on Meeting the MDG (March 2002)

[2] Wetlands and Remediation. Second International Conference. Sept. 5-6, 2001. Burlington Vermont

During the last three decades, the German government, through the German Agency for Technical Cooperation (GTZ), has supported economic and social development in the Philippines. One of GTZ's focal sectors is Water, Sanitation and Solid Waste Management. Complemented by the wide experience of several parent sector projects, the GTZ Water Program pioneered the philosophy of ecological sanitation (ecosan), which mainly supports the implementation of innovative options for low-cost rural water supply and sanitation that includes dry sanitation systems, constructed wetlands, decentralized wastewater treatment systems, biogas technology and rainwater harvesting. In general, the advisory services offered by Program on all its intervention levels fall on the context of Integrated Water Resources Management.

GTZ has forged a partnership with competent and experienced academic institutions, namely the University of the Philippines Environmental Engineering Unit and the UFZ Centre for Environmental Research Leipzig-Halle of Germany, to implement the first Vertical Flow Reed Bed System in the City of Bayawan, Negros Oriental Province. This project is currently being implemented through a participatory approach, where the main stakeholders are involved in planning, design, and construction as well as in the operational phase. The plant shall serve as a pilot measure to demonstrate the applicability and efficiency of engineered reed beds as a low-cost alternative technology for wastewater treatment.

GTZ likewise has a standing cooperation agreement with ADB under the "Development of Poor Urban Communities Sector Project (DPUCSP)." Within the framework of DPUCSP, the GTZ Water Program shall promote low-cost technologies for sanitation and wastewater treatment. The potential for upscaling and replicating the technology to other DPUCSP sites is essentially a primary interest of the cooperation.

Description of the Technology

Natural Treatment Systems

A natural treatment system would refer to any unit process, which would involve water, soil, plants, microorganisms and interaction with the atmosphere. If we remove the plants from this equation, then this would refer to any of the conventional biological treatment systems we are familiar with. The addition of plants in this stoichiometry would therefore differentiate it from other systems. In an effort to apply rigidity to the study of this field of Environmental Engineering, different authors have come up with classifications for the different processes under the general label of "natural treatment systems". We can generally classify them according to the following headings, namely (a) Aquatic Treatment Units; (b) Wetland Treatment Units; and (c) Terrestrial Treatment

Natural treatment systems, specifically constructed wetlands, provide a good and robust solution for the rising wastewater problem in the Philippines. Compared to common treatment facilities, wetlands are lower in cost investment, lesser to maintain, and are ideal for densely populated rural or suburban areas.

Engineered Reed Beds

Wetland systems have been used in many applications including treatment of domestic wastewater, septage, highly concentrated organic wastes from food industries, metal processing wastes, and as a polishing step for secondary treatment systems before final discharge. Engineered Reed Beds are sub-surface flow systems that use reeds in densely planted beds as a treatment system.

In Europe, the concept and application of constructed wetlands is generally different from those that exist in North America and Australasia. In Europe, natural treatment systems such as reed beds are designed to provide secondary treatment for village sized communities of up to 1000 population equivalent.; while in North America, they are designed for tertiary treatment of larger populations. Another difference is that in Europe, the systems are nearly always specifically excavated and planted, whereas in America they are often created from existing natural wetlands.[3]

The use of reeds for the treatment of sewage was first investigated in Germany by Seidel and Kickuth in the 1960's. Since then, about 500 reed bed treatment systems have been constructed in Western Europe since 1984. In general, the experiences gained in the years since, show that BOD (Biochemical Oxygen Demand) removal is 80 to 90%, with typical outlet concentrations of 20 ppm; total N removal is 20 to 30%; and total P removal is 30 to 40%. A general problem is surface flow of the feed caused by the hydraulic load exceeding the permeability of the bed. It is important to note that the pre-engineering of reed bed treatment systems is critical. These systems are not flexible in terms of adjusting to excessive load.

Mechanisms for Engineered Reed Beds

In the case of Engineered Reed Bed Systems, rhizodegradation is the main mechanism for the removal of organic contaminant. Rhizofiltration explains the retention of inorganic contaminants in the reed bed. The reeds which are used for reed bed construction are rhizome bearing macrophytes. These structures in the root system or rhizosphere provide the microenvironment for aerobic and anaerobic degradation of various compounds. Together with the root exudates from the reeds, a unique environment for degradation is produced. The other mechanisms also come into play in varying degrees. These mechanisms give the reed bed system a distinct advantage over other conventional biological systems in the degradation and stabilization of recalcitrant compounds and difficult-to-biodegrade or persistent compounds, which are often also toxic compounds.

The advantages of Engineered Reed Treatment Systems include (a) minimal operating cost due to low energy required; (b) possible treatment solution for the removal of recalcitrant compounds; and (c) possible treatment solution for very small flows, previously untreated.

Practical Applications of Engineered Reed Beds in the Philippines

Detergent Wastewater

A pilot reed bed for research purposes was constructed by the University of the Philippines in Nasugbu, Batangas. Wastewater from a laundry service was treated in this bed. The main contaminant was surfactants. The observed removal efficiency approached 90%. A 5 day retention time was used and measured through tracer studies.

[3] P.F Cooper. The Use of Reed Bed Systems to Treat Domestic Sewage: The European Design and Operations Guidelines for Reed Bed Treatment Systems. CRC Press. 1993

The research also involved the comparison between *Phragmytes karka* and *Phragmytes australis.* It was observed that *Phragmytes karka* performed better in the comparison trials. The removal efficiency and consistency of performance was better for *karka.* [4]

Distillery Slops

An engineered reed bed system for the treatment of alcohol distillery waste is presently operated in Nasugbu, Batangas. The main contaminant of concern in alcohol production is the compound Melanoidin, which results from the Maillard reaction between sugars and amines upon heating. It has a complex polymeric structure whose molecular size is affected by pH and temperature.[5] Melanoidin would then refer to a family of highly colored compounds generated during the alcohol production process. Conventional treatment methods do not provoke the breakdown of this colored substance. Reed bed treatment systems offer a possible treatment method for melanoidin contaminated wastewater. The combined aerobic and anaerobic structure of the rhizosphere of the bed gives it a higher capability to handle the recalcitrant melanoidin.

Housing Resettlement (On-going Project)

The Fishermen's Village is one of the major projects undertaken by the City of Bayawan that aims to provide a decent and low-cost shelter to beneficiaries affected by the Coastal Bay Development Project. The housing relocation site is accessible to the source of livelihood of the fishermen who composed more than 50% of the informal settlers along 4 coastal barangays. A total of 715 households will be resettled in the 7.4-hectare relocation village. An engineered reed bed treatment system is under construction for the said village. This system uses two reed bed systems in series, a vertical reed bed followed by a horizontal flow reed bed. The use of a vertical reed bed will enhance disinfection and removal of nutrients Nitrogen and Phosphorus.

With the implementation of the Philippine Clean Water Act, highly urbanized communities and rural villages are required to connect to available sewerage systems for the treatment of their generated wastewater. Considering the financial constraints for local government units to access or construct conventional treatment systems, the application of engineered reed beds are deemed appropriate.

Benefits and Expected Results

Costs and Energy

Aside from the intrinsic attraction of the "naturalness" or back-to-nature approach of these systems, one major advantage of natural treatment systems is the low operational costs due to the low energy requirements in operating and maintaining the system. Mechanical Aeration is not necessary and is substituted by plant respiration. Initial capital costs for the construction of the system would be comparable with any of the conventional systems. A drawback of natural treatment systems is the need for extensive land area. This may vary from 1 – 5 m^2 per person served. There is also the need to isolate the system from the surrounding environment. This would mean the

[4] Mark T.Q. Mulingbayan. Treatment of Laundry Wastewater using Horizontal Flow Engineered Reed Beds. Masters Thesis. University of the Philippines. College of Engineering. 2005

[5] Ernesto J. del Rosario. Chemical and Microbial Decolorization of molasses-derived melanoidin. Kimika. 9: 65-72 . 1993

need for an impermeable barrier such as plastic or clay lining. Once the system has been built though, the operational costs are substantially lower than conventional systems such as a comparable Activated Sludge Plant.

Sustainable System Operation and Maintenance

The operation and maintenance of engineered reed beds are inherently simple and inexpensive. If the site topography permits, gravity flow through the system affords a no-cost operation of the system. The system is remarkably low maintenance since the reeds are not cut nor trimmed. In cases where the site topography is flat, a pump may be needed to provide a lift to the liquid.

The operation and maintenance of the engineered reed bed encourages the participation of the local community, which could work in 2 models; namely through a Barangay Council or through a Resident's Association.

<u>O&M through a Barangay Council.</u> The community directly benefiting from the reed bed system can assign properly trained staff to take turns in ensuring the proper functioning and maintenance of the treatment facility. Since this task will require only part-time work from the staff, this may easily be absorbed by the current plantilla of the barangay.

<u>O&M through a Residents' Association.</u> A team of trained staff from the residents association may be tasked to manage the operation, maintenance and tariff collection of the treatment facility. The monthly salary of the staff may be sourced from the dues the residents pay on a yearly basis. Alternately, it may also be sourced from an added tariff attached to the water bill or solid waste collection bill of the community.

It is estimated that when the system is properly functioning, the time required for daily inspection would only take half an hour.

Lessons Learned

Treatment of Wastewater using Engineered Reed Bed Systems has been demonstrated in the Philippines (Nasugbu, Batangas) using the Horizontal Flow System and planted with *Phragmytes karka* and *Phragmytes australis*. The efficiency of the system was demonstrated using surfactant contaminated laundry wastewater. In other countries, the use of this system has been demonstrated for domestic wastewater treatment. The application of this system in the Philippines may be more efficient due to higher ambient temperatures, which means faster metabolic rates of microbial systems in the rhizosphere. The first such system will be built in the city of Bayawan, Negros Oriental, for a community of 700 households living in government supported low cost housing.

Appendix

References

1. P.F Cooper. The Use of Reed Bed Systems to Treat Domestic Sewage: The European Design and Operations Guidelines for Reed Bed Treatment Systems. CRC Press. 1993
2. Introduction to Phytoremediation. USEPA. National Risk Management Research Laboratory, Cincinnati, Ohio 45268. February 2000
3. Mark T.Q. Mulingbayan. Treatment of Laundry Wastewater using Horizontal Flow Engineered Reed Beds. Masters Thesis. University of the Philippines. College of Engineering. 2005
4. Ernesto J. del Rosario. Chemical and Microbial Decolorization of molasses-derived Melanoidin. Kimika. 9: 65-72 . 1993

Supporting Information

1. Abstract of paper

Mark T.Q. Mulingbayan. Treatment of Laundry Wastewater using Horizontal Flow Engineered Reed Beds. Masters Thesis. University of the Philippines. College of Engineering. 2005

The removal of chemical oxygen demand (COD) and anionic surfactants (as linear alkylbenzene sulfonates, or LAS) from commercial laundry wastewater in horizontal subsurface flow constructed treatment wetlands was investigated in two pilot-scale reedbeds planted with two species of the common reed, *Phragmites australis* and *Phragmites karka*, in four experimental runs at varying hydraulic gradients and theoretical hydraulic retention times (HRT). In one run, a dye tracer test using Rhodamine WT was performed for both reedbeds to compare the theoretical and actual HRT.

The COD and surfactants removal efficiencies of the *P. karka* reedbed ranged from 76.8% to 85.6%, and 90.1% to 91.9%, respectively, slightly better than that of the *P. australis* bed with removal efficiencies of 74.8% to 81.82% for COD and 86.6% to 90.9% for surfactants, for theoretical HRT's of 4 to 5 days.

The dye tracer breakthrough curve generated in one of the runs showed the actual HRT to be shorter than the theoretical hydraulic retention time as derived from hydraulic gradient and estimated permeability using grain size distribution data, due to clogging of the inlet and surface tracking, typical of soil-based reedbeds fed with significant quantities of suspended solids and organic load.

From a maintenance point of view, *P. karka* proved to be the more resilient species, but due to its larger aboveground biomass, takes up more water than P. australis, and may be disadvantageous if water recovery for reuse is a priority.

2. Photo Log of Reed Bed Trials

Figure 3-1 Construction of reedbeds, showing elevations of the floor. The outlet zone is in the foreground.

Figure 3-2 Laser-level equipment used to ensure proper elevations during construction.

Figure 3-3 The reedbeds after HDPE-liner installation, before placement of soil media.

Fig. 4-__ Immediately after planting Dec 2001

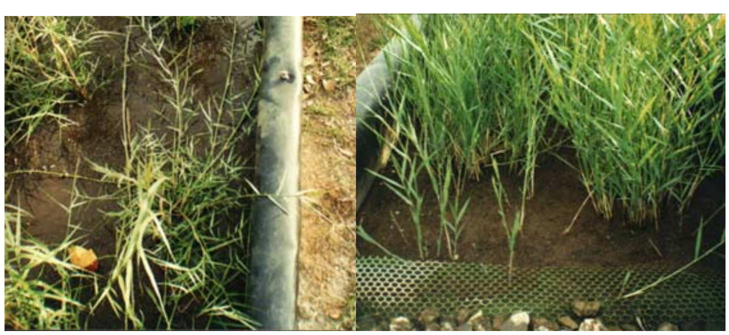

Figure 4-__ Comparative growth spread mechanisms. P. karka (left) sends aboveground stems on the surface which grow shoots, while P. australis (right) sends underground rhizomes and new shoots erupt away from the mother plant.

Fig. 4-____ Between Dec 2001 and Aug 2002

Fig 4-__. August 2002.

Fig. 4-___. November 2002. Reeds fully mature

3. Results of Dye Tracer Studies

The dye tracer test was performed in February2005, midway during the third experimental run. Trace amounts of Rhodamine WT were detected prior to pulse feeding due to a past attempt at a dye tracer trial in the previous month using only 100 mg of RWT dye. These levels were found to be negligible and were expected to be depleted in time. The amount of Rhodamine WT used for the February 2005 trial was 1,000 mg active ingredient per bed.

The breakthrough curve for both beds manifested an early peak followed by a long declining tail, indicating an almost plug flow condition with considerable dispersion, validating reported dye tracer response curve behavior described in numerous literature. (See Figure 4-2)

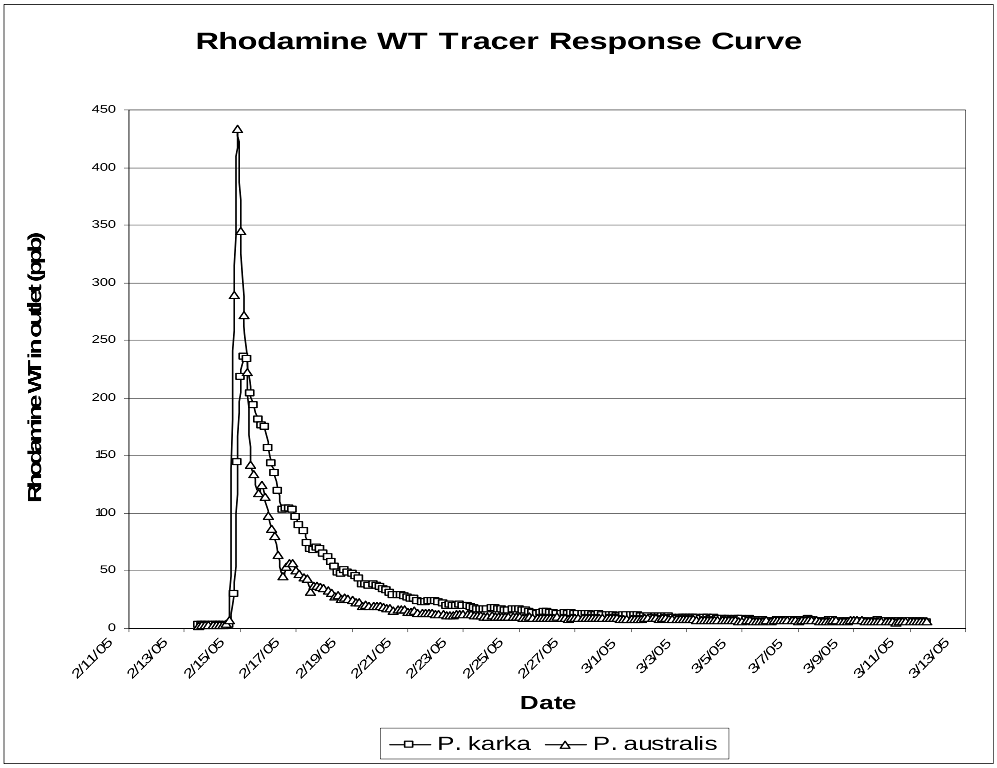

Figure 4-2. Dye Tracer Response Curve

Mechanisms for Contaminant Removal

To explain the effectiveness of using plants in the removal of various contaminants, it is important to know the different possible mechanisms involved for contaminant removal or stabilization[6]. The following mechanisms explain the process of contaminant removal.

1. Phytoextraction

2. Phytostabilization

3. Phytodegradation

4. Phytovolatilization

5. Rhizofiltration – refers to the adsorption or precipitation onto plant roots or absorption into roots of contaminants that are in solution surrounding the root zone, due to biotic or abiotic processes. Plant uptake, concentration, and translocation might occur, depending on the contaminant. Rhizofiltration first results in contaminant containment, in which the contaminants are immobilized or

[6] Introduction to Phytoremediation. USEPA. National Risk Management Research Laboratory, Cincinnati, Ohio 45268. February 2000

accumulated on or within the plant. Contaminants are then removed by physically removing the plant.

6. Rhizodegradation – refers to the breakdown of an organic contaminant in soil through microbial activity that is enhanced by the presence of the root zone.

7. Rhizodegradation is also known as plant assisted degradation, plant-assisted bioremediation, plant aided in-situ biodegradation, and enhanced rhizosphere biodegradation. Root zone biodegradation is the mechanism for rhizodegradation. Root exudates are compounds produced by plants and released from plant roots. They include sugars, amino acids, organic acids, fatty acids, sterols, growth factors, nucleotides, flavanones, enzymes and other compounds. The microbial populations and activity in the rhizosphere can be increased due to the presence of these exudates, and can result in increased organic contaminant biodegradation in the soil. Additionally, the rhizosphere substantially increases the surface area where active microbial degradation can be stimulated. Degradation of the exudates can lead to cometabolism of contaminants in the rhizosphere. Plant roots can affect soil conditions by increasing soil aeration and moderating soil moisture content, thereby creating conditions more favorable for biodegradation by indigenous microorganisms. Thus, increased biodegradation could occur even in the absence of root exudates. One study raised the possibility that transpiration due to alfalfa plants drew methane from a saturated methanogenic zone up into the vadose zone, there the methane was used by methanotrophs that cometabolically degraded TCE.

The principles behind the removal process are the following:

1. The root system of the reeds grows vertically and horizontally, opening up the bed to provide a hydraulic pathway.
2. Within the rhizosphere (the small area surrounding the rhizomes), large populations of common and unique, aerobic and anaerobic bacteria reside, which effect the biological breakdown of the organic components of the wastewater.
3. It has been claimed that oxygen is passed to the rhizosphere via the leaves and stems of the reeds through the hollow rhizomes and out through the roots to provide some of the oxygen needed by the aerobic bacteria. The rate at which this occurs has not yet been determined.
4. Suspended solids in the sewage are aerobically composted in the layer above-ground of straw debris formed from dead leaves and stems.