Best Management Practice Fact Sheet
on
Constructed Wetlands

I. What is a Constructed Wetland?

The horizontal subsurface-flow constructed wetland (HSSF-CW) is a type of engineered wetland which is typically employed for treatment sewages and even for treatment of industrial effluents. Such wetlands include 'Reed Beds' and 'Root-zone' treatment methods devised to obtained environmental duty from the macrophytes cultivated in trenches or on beds having saturated with sewages or wastewaters. HSSF-CW is normally a shallow bed, about 0.3-0.8 m deep filled with the layers of gravel (<15 mm) and sand (or sandy loam) of porosity around 42%. In certain situations, formation of the "root zone" need to be selectively created by mixing finer fraction with sandy soil or compost with local soil.

The bed could be of any rectangular or curvilinear geometric shape in plan, preferably having four to five times longer flow path when compared with the distance between two parallel edges. In several situations, especially when percolation of sewages and industrial effluents should be minimised to prevent groundwater and sub-surface strata from contamination; the bottom and side walls of HSSF-CWs need to be made impervious by lining it with clay layers or polythene membranes. Alternately, if the underneath strata bares properties that are not favourable for installing flexible or subsiding impervious layers; the leak-proofing of wetland bed may be achieved by tiling or installing reinforced cement concrete layer coated with leak proofing chemical additives. Typically, the impervious layer is expected to achieve hydraulic conductivity of 10^{-8} to 10^{-9} m/s (Arceivala and Asolekar, 2006).

The inlet and outlet zones of the HSSF-CWs are rather important from the prospective of maintaining desirable hydraulic flow regime on one hand and ensuring uninterrupted operation on the other hand. Therefore, the both zones are filled with larger gravels (50-100 mm). A water level regulation chamber is also normally devised before final discharge. Arceivala and Asolekar (2006) describes the engineering design of the system complete with engineering details of baffle in the exit chamber. The adjustable heights of the baffle helps in maintaining the loss of head to the tune of approximately 50 mm of water throughout the operation of HSSF-CW. Pre-treatment (conventional primary treatment or lagoons) of the sewages or industrial effluents is also highly recommended in all the cases wherein the macrophyte beds would receive raw sewages or effluents.

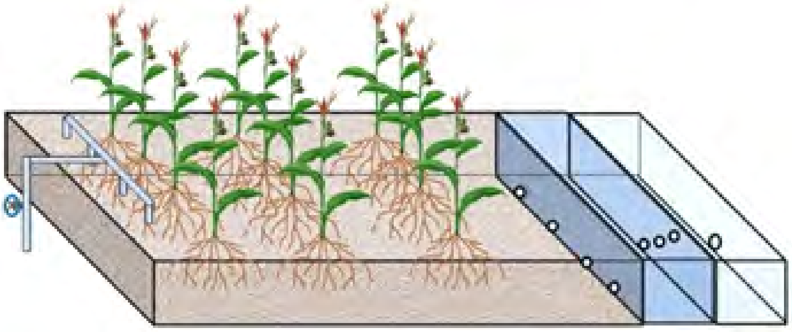

Fig 1: Isometric view of HSSF-CW at IIT Bombay

Fig 2: Photograph of HSSF-CW at IIT Bombay

II. Where can Constructed Wetlands be used?

In the light of shortages of water in several parts of the World (including in Asia), communities are searching for the alternatives which would augment their water resources. In that context, clearly, the engineered CWs have attracted attention of environmental engineers and scientists by the virtue their abilities of treating sewages and wastewaters at phenomenally low operation and maintenance (O&M) costs as well as low power requirements. Consequently, they have been favourably looked upon in the countries which have the natural advantage of tropical climate and warm weather.

The conventional mechanised sewage treatment systems, including activated sludge process, trickling filters and extended aeration systems, turn out to be rather expensive in terms of, both, the installation as well as operation and maintenance costs. The engineered variants of CW have been investigated thoroughly in Saph Pani Project because the peri-urban and small communities seem to be willing to own and operate their wastewater treatment systems based on these eco-centric approaches.

Interestingly, in the recent past, communities seem to favour the engineered CW, owing to its capabilities of providing adequate treatment to wastewaters in conjunction with supplementing nutrition to the food baskets of the communities managing the systems as well as generating adequate water for irrigation of farms, cultivation of fodder and enhancement of agro-forests for generation of timber and biomass energy. Above all, the engineered CWs blend well with the agricultural, peri-urban, and rural ecosystems

III. How do Constructed Wetlands Work?

Wastewater come in contact with a network of aerobic, anoxic and anaerobic zones. The roots and rhizomes would dissolve additional oxygen. As a result, zone around rhizo-sphere remains aerobic and wastewater gets treated through microbial degradation processes as well as with help of physical and chemical processes. Attached and suspended microbial growth is responsible for the removal of soluble organic compounds, which are degraded aerobically as well as anaerobically. The uptake of organic matter by the macrophytes is negligible compared with biological degradation.

In general, the two main carbon source for synthesis of cell are the organic carbon and carbon dioxide. Micro-organisms which use organic carbon for the formation of cell tissue are called heterotrophs and are better suited for decreasing the carbonaceous BOD and exhibit higher metabolic rates. Micro-organisms those derive carbon for cell synthesis from carbon dioxide are called autotrophs. Both groups use light or redox reaction as energy source for cell synthesis.

Organic compounds are also degraded by anaerobic and anoxic biologically mediated reactions prevalent in deeper zones of the HSSF-CW with the help from bacteria attached to the media surfaces. Nitrogen is removed in the CW by nitrification and denitrification and through plant uptake. Ammonia is oxidised to nitrate by nitrifying bacteria in aerobic zones, and nitrates being converted to gaseous nitrogen by denitrifying bacteria in anoxic zone.

Two important aspects are to be kept in mind while designing HSSF CWs; (i) organic removal parameter, and (ii) hydraulic flow considerations. The design criteria for BOD removal is approximated by first-order, plug flow kinetics (Arceivala and Asolekar (2006) and present research). Therefore, the classical solution of first order reaction can be suitably modified for design of HSSF-CW aimed at treatment of sewages. The design parameters can be estimated with the help of mass-balance model based on the pseudo-first-order plug flow kinetics for removal of BOD_5 (Arceivala and Asolekar, 2006). The classical solution of first order reaction can, thus, be suitably modified, as depicted in equation (1-3), for designing the HSSF CW aimed at treatment of sewages.

$$(1) \qquad C_\tau = C_o . e^{-(K_{BOD} . \tau)}$$

The above equation can also be employed for estimation of hydraulic retention time (τ) of the HSSF CW by rearranging it in the following manner:

$$(2) \qquad \tau = (\ln C_0 - \ln C_\tau)/(K_{BOD})$$

Further, the foot-print area for the HSSF CW can be estimated by modifying equation (2) as follows:

$$(3) \qquad A = Q . (\ln C_0 - \ln C_\tau)/(\eta . H . K_{BOD})$$

where,

C_τ = outlet BOD_5. mg/L
C_o = inlet BOD_5. mg/L
K_{BOD} = reaction rate constant for removal of BOD_5, day^{-1}
τ = $(V . \eta / Q)$ i.e. hydraulic retention time, day
Q = average flow, m^3/day
η = porosity of packed bed (void fraction v/v)
V = volume of packed bed $(H . A)$, m^3
A = plan area of packed bed, m^2
H = bed depth, m

The above design approach can also be analogously used for removal of COD and suspended solids as well as for denitrification and pathogen removal by substituting the appropriate K values.

IV. Performance

Typically, CW systems are designed for removal of organics and, in some cases, nutrients. However, it is undeniable that the systems significantly enhance the microbiological quality of the wastewater in terms of pathogen reduction during the course of treatment process.

The conventional mechanised sewage treatment systems, including activated sludge process, trickling filters and extended aeration systems, turn out to be rather expensive in terms of, both, the installation as well as operation and maintenance costs.

The Research Station named “Exploration”, based on horizontal sub-surface flow constructed wetland (HSSF-CW) technology, has been established and commissioned on IIT Bombay Campus in November, 2013 utilizing the research funds provided by the Saph Pani Project (Fig 1 & Fig 2). The field-scale investigations are being conducted in the pilot plant. Over the past ten months, efforts are being made to treat sewage from IIT Bombay Campus. The treatment system has been in the gradual process of stabilization and the changes in its behaviour is being continuously tracked by monitoring the physico-chemical and bacteriological parameters in the raw versus treated sewage.

The strategies are being developed aimed at enhancement of performance of CWs through a focused research conducted on the campus of IITB at the Research Station. The key issues impairing the system performance were identified during the field research. The laboratory research focused some of the specific issues associated with the choice of plant species and performance routines with the help of potted plants to simulate CW-like operation. The following key points are being addressed in our research in IITB:

- Selection of the appropriate plant species and development of the operation routines for better removal of pollutants.
- To investigate different media (locally available) to improve the performance of HSSF-CW.
- Development of a rational strategy of aimed at removal of nutrients and carbonaceous pollutants from sewages with the help of HSSF-CW.
- Exploration and assessment of various options for gainful utilization of the treated sewages and effluents and biomass generated from the CW.

In summary, the research at IIT Bombay, supported by the Saph Pani Project, has underscored the fact that the CW systems can be effectively combined with advanced tertiary treatment alternatives and the resulting high quality treated effluents can be gainfully recycled into production and sanitation applications.

On one hand, the Research Station has helped IITB to explore potential ways of enhancing performance of constructed wetland-like natural treatment systems that can provide economic solutions for the problems currently being faced while providing sanitation in small peri-urban, rural as well as remote tribal and rural locations. On the other hand, it is hoped that this approach will demonstrate the significance of constructed wetland as a sustainable and eco-friendly alternative among a plethora of treatment methods that claim to be providing safe and sustainable technologies to protect water resources in a developing country like India.

In addition, engineered CWs provide habitat to many wetland organisms. Our research and implementation has also suggested that CW-based treatment systems do provide numerous benefits, in addition to the wastewater treatment, such as provision of wildlife habitats Also, CWs enhance aesthetic appeal of the landscapes because they can be built to fit harmoniously into the rural landscapes and urban fringes. . . . . Our work is in progress.

V. Limitations

The CW-based natural treatment systems can hopefully provide economic solution for the problems currently faced while providing sanitation in the remote tribal and rural locations. Also, these systems may provide the sustainable and eco-friendly alternatives among a plethora of treatment methods that claim to be providing safe and sustainable technologies to protect water resources in a developing country like India. The only perceived technological limitation is of larger foot-print as compared with conventional mechanised treatment systems. However, this limitations is typically encountered in metropolitan cities and found to be a good alternative in rural and peri-urban locations where space is not a constrain (Asolekar et al., 2013).

VI. Approximate Costs

The capital cost for construction of HSSF CW includes various civil works for establishment of primary treatment units, CW bed, treated water collection chamber and the cost associated with media filled in the CW bed. For estimation of capital costs, a study has been conducted in rural India for establishment of 200 m^2 of CW bed. The capital cost may vary from place-to-place due to variability of labor charges and transportation costs of construction materials to the construction site. Normally the construction cost remains 40% higher in Indian cities as compared with the towns and villages. If the land costs (highly variable) are excluded from the cost estimation, the capital cost for CW system having plan-area of 200 m^2, comprising of wetland bed, sludge bed, sewage settling tank and fencing, worked out to be approx. INR 1 million (≈USD 17,000) i.e. about INR 5,000 (≈USD 100) per m^2 plan area of CW bed. The amount of wastewater treated in 200 m^2 area will depend on strength of organic matter (BOD) – which may be calculated with the help of design equations.

The O&M costs are far lower for CW-system as compared with mechanized systems. The typical O&M activities involved in successful implementation of CW systems are regular cleaning of primary treatment units, cutting and pruning of vegetation grown in CW bed and managing the treated water for further use. More importantly, the unskilled person can handle the O&M of CW-based systems and the number of persons required depends upon the size of treatment systems. Based on the experienced gained from India wide survey of CWs, one person was found sufficient for O&M activities of the systems having the treatment capacity of 50-80 m^3 per day.

References

Arceivala, S.J., Asolekar, S.R. Wastewater treatment for pollution control (3rd Edition, 10th Reprint) Tata McGraw Hill Education (India) Pvt. Ltd., New Delhi, 2006.

Asolekar, S.R., Kalbar, P.P., Chaturvedi, M.K.M., Maillacheruvu K.Y (2013) Rejuvenation of Rivers and Lakes in India: Balancing Societal Priorities with Technological Possibilities, Reference Module in Earth Systems and Environmental Sciences, from Comprehensive Water Quality and Purification, Volume 4, pages 181-229, 2014

Key-words

Constructed Wetlands, Subsurface-Flow, Natural Treatment Systems, Wastewater Treatment and Reuse, Eco-centric Technology

For More Information

Prof. Shyam R. Asolekar

Indian Institute of Technology Bombay
Mumbai, INDIA
Email: asolekar@iitb.ac.in

Compiled & Edited by :

Dr V C Goyal

National Institute of Hydrology
Roorkee, India
Email: vcg@nih.ernet.in

Compiled by WP-1 Group of "Saph Pani" Project; Edited & printed by WP-7 Group at
National Institute of Hydrology, Roorkee, India

Project supported by the European Commission within the Seventh Framework Programme Grant agreement No. 282911

Contact: info@saphpani.eu
Website: www.saphpani.eu