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Constructed wetlands for wastewater treatment: A review

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ABSTRACT

Wastewater treatment is a problem that has plagued man ever since he discovered that discharging his wastes into surface waters can lead to many additional environmental problems. Strategies for control of water pollution have focused mainly on implementation of expensive and energy intensive conventional treatment technologies. The limited successes of such strategies can be attributed to the high capital investment requirement, continual replacement and high operation costs. In recent years, constructed wetlands systems have emerged as a low-cost high-performing wastewater treatment technology compared to conventional treatment systems. There is a growing interest to develop and adopt this technology for water pollution control in India as well. This paper gives some introductory information on the concepts, pollutant removal mechanisms, engineering design, construction, vegetation and applications of constructed wetlands for wastewater treatment.

KEYWORDS

Constructed wetlands;
Macrophytes;
Wastewater treatment.

INTRODUCTION

Water, the most abundant and wonderful natural resource, is extremely essential for the survival of all living organisms. Rapid industrialization and urbanization over the past decades have generated increasing amounts of wastewater, resulting in environmental deterioration and pressure on reliable water resources. The Water (Prevention and Control of Pollution) Act, 1974 leads to the construction of many new wastewater treatment facilities across the country to help control water pollution. In the future add-on processes will be needed to upgrade many of these treatment facilities.

Various methods are available for wastewater treatment starting from conventional ponds to anaerobic lagoons. Recently advanced technologies including physical, chemical and biological treatments have been developed for the sewage water treatment like, ion exchange, filtration, coagulation, precipitation, adsorption etc. Among the biological systems, constructed wetland technology is a new technology and it is a cheaper alternative for waste water treatment as it uses local resources. Aesthetically it is a more landscaped looking wetland site compared to the conventional wastewater treatment plants. This system promotes sustainable use of local resources, which is a more environment friendly biological wastewater treatment system. Apart from, compared with conventional treatment systems, this constructed wetland systems having advantages such as: can be established in the same place, where the wastewater is produced; can be maintained by relatively untrained personnel; have relatively low energy requirements; and are low cost systems. Since the publication of first research report on the use of aquatic plants for pollution control[32], research into constructed wetlands has expanded rapidly, but this novel approach remains a developing technology even today with many of the key processes and their rates and interactions are poorly understood and standardized.

CONSTRUCTED WETLANDS

Constructed wetlands are engineered systems that have been designed and constructed to utilize natural processes involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters[35]. They are designed to take advantage of many of the processes that occur in natural wetlands but do so within a more controlled environment. Some of these systems have been designed and operated with the sole purpose of treating wastewater, while others have been implemented with multiple-use objectives in mind, such as using treated wastewater effluent as a water source for the creation and restoration of wetland habitat for wildlife use and environmental enhancement.

FLOW TYPES IN CONSTRUCTED WETLAND TECHNOLOGY

Constructed wetlands have positive characteristics of a natural wetland and can also be controlled to eliminate the negative aspects of natural wetlands. There are several types of constructed wetlands: surface flow wetlands, subsurface flow wetlands and hybrid systems that incorporate surface and subsurface flow wetlands.

Surface flow wetlands

These systems typically consist of basins or channels, with some sort of subsurface barrier to prevent seepage, soil or another suitable medium to support the emergent vegetation, and water at a relatively shallow depth flowing through the system. The shallow water depth, low flow velocity, and presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels minimize short circuiting[10]. In surface flow wetlands, the near-surface layer is aerobic while the deeper waters and substrate are usually anaerobic. The advantages of surface flow wetlands are that their capital and operating costs are low, and that their construction, operation, and maintenance are straightforward. The main disadvantage of surface flow systems is that they generally require a larger land area than other systems.

Subsurface flow wetlands

A subsurface wetlands system consists of channels (or) basins that contain gravel (or) sand media which will support the growth of emergent vegetation, the bed of impermeable material is sloped typically between 0-2 per cent. Wastewater flows horizontally through the root zone of the wet land plants about 100-150 mm below the gravel surface. Treated effluent is collected in an outlet channel or pipe[10]. Subsurface flow systems are called by several names including vegetated submerged bed, root zone method and microbial rock reed filter systems. Advantages of subsurface flow wetlands over the surface flow wetlands were reported by EPA manual[12],

- As water surface is maintained below the media surface, there is little risk of odor, direct exposure and insects
- The filter media provides greater available surface area for wastewater treatment
- subsurface flow wetlands generally have smaller in area than surface flow wetlands for the same wastewater conditions
- The subsurface position of water and the accumulated plant debris on the surface of the subsurface flow wetlands offer greater thermal protection in cold climate than surface flow wetlands.

Hybrid systems

Single stage systems require that all of the removal processes occur in the same space. In hybrid or multistage systems, different cells are designed for different types of reactions. Effective treatment of wastewater may require a sequence of different wetland cells to promote aerobic and anaerobic degradations.

WETLAND MACROPHYTES

The plants growing in wetlands (often called wetland plants (or) macrophytes) are adapted to grow in water saturated soils. It is thus an intrinsic property of wetlands that they are vegetated by wetland plants. Constructed wetlands for wastewater treatment may be classified according to the life form of the dominating macrophyte into systems with free-floating, rooted emergent and submerged macrophytes[6]. The macrophytes have enormous function in wastewater treatment such as, gas transport, release of oxygen by roots, influence on soil hydraulic conductivity, uptake of nutrients and other functions[5]. The macrophytes also provide a larger surface area for attached microbial growth. The macrophytes have an additional function that is not related to the treatment of the wastewater, which may be significant at specific sites. In large system, the wetland vegetation may support a diverse wildlife, including birds, reptiles etc. It is possible to select nice-looking wetland plants like the yellow flag (*Iris pseudacorus*) or canna-likes and in this way making sewage water treatment aesthetically pleasing.

TREATMENT TECHNOLOGIES

This technology involves the use of plants for wastewater treatments although plants do not always play a primary role in this process. The pollutants in such systems are removed through a combination of physical and biological reactions, which occur in the aerobic and anaerobic zones of wetlands.

Aerobic process

In most wetlands where there is free water surface aerobic condition exist throughout the water column, but condition quickly change to anaerobic below the soil surface, however, if the water level is below the soil surface, the area of the soil above the water level is also aerobic. Under flooded conditions, diffusion of oxygen through floodwater maintains aerobic conditions at the soil-floodwater interface[30]. In addition when vegetation is present an aerobic zone exists around the roots of each plant as the plant transports oxygen to its root as reported by Grosse[17] and Michand and Richardson[27]. Similarly Wieder[36] and Hedin[18] reported that wetlands are typically constructed so that flow occurs across the surface of an organic substrate, which has been planted with cattails, and treatments occur in the aerobic zone. Organic matter mainly removed by the breakdown of soluble BOD during microbial respiration. Nitrification occurs in aerobic zones of soil water interface and root zone. Removal of metal ions occurs primarily in the aerobic zone through a variety of reactors including adsorption, chelation and ion exchange. Ion exchange reaction often involves the exchange of a hydrogen ion for the metal ion, therefore causing pH to decrease, as the pH decreases the efficiency of the aerobic process decreases.

Anaerobic process

In most wet lands anaerobic condition develop in the saturated zone, below the soil / water surface, although exchange reactions can still occur in anaerobic zone, the primary reaction of importance for metal removal in sulphate reduction. Bolis et al.[4] reported that sulfate reducing bacteria are ubiquitous and tolerate a wide range of environmental condition. Denitrification also occurs in anaerobic zones of soil water column.

Microbial process

Microorganisms in the root rhizosphere region play a major role in waste water treatment, the passage of waste water treatment, through the medium forms bacterial film on the bed medium surface, similar to sewage sludge in waste water treatment plants, and has a great diversity of bacteria capable of breaking down a wide variety of organic molecules, adsorption of molecules on to the highly reactive surface is the most likely first step followed by accumulation of the bacteria if necessary, leading to the breakdown of the organic molecules to simple intermediates and in many cases complete breakdown to CO_2, methane and water was reported by Gray[16].

Jensen et al.[22] reported that purification of the wastewater occurs through the microbial interactions on the plant stalks as well as through reaction in the water and upper sediment zone. Microbial growth on plant roots, chemical process and filtrations of the substrate itself combine to provide the water cleaning properties in the system[23]. The microbial population in the rhizosphere region of the plant root system is dominated by bacteria, however bacteria has relatively low enzymatic activities within the organic substrates tested and would therefore, be expected to degrade most of the simpler organic material i.e. those contributing most to the biochemical oxygen demand. By contrast, the fungi and actinomycetes, although fewer in number, have a wider range of hydrolytic activities. Consequently they would be expected to degrade many of the larger molecules that contribute to the chemical oxygen demand[15].

POLLUTANT REMOVAL MECHANISM IN CONSTRUCTED WETLANDS

In a reed bed treatment system pollutants are removed from wastewater by a combination of physical, chemical and microbiological processes. Reed beds have more diverse activities than conventional biological treatment systems. Although the mechanisms of reed bed treatment are not yet fully understood, some interesting discoveries have been made over the past few years. The mechanisms (physical, chemical and biological) involved in the purification of effluent by reed bed system are presented in TABLE 1.

The suspended solids removal mechanism consists of sedimentation, filtration and adsorption. Tchobanoglous and Eliassen[34] reported straining as the mechanism of removal of suspended solids which appears to be more pronounced in conventional sand filters, and also suggested that transport and attachment (by various process, sedimentation, adsorption *etc.,*) are the mechanism in deep bed filtration where full bed depth is utilized for removal of residual suspended solids. Suspended solids removal is almost entirely due to physical processes rather than biological processes associated with the microbial community or with the plants[8]. Metcalf and Eddy[26] reported that the surface forces responsible for the reduction of suspended solids include Vander Waal's force of attractions and electric forces, which may be attractive or repulsive depending on the surface chargers, particles smaller than pore size may be trapped within the filter by chance contact. Gersberg et al.[13] and Bavor et al.[2] reported that unplanted systems acting as controls were as efficient as the planted system in reducing the suspended solids from primary and secondary treated effluent.

TABLE 1 : Pollutant removal mechanisms in constructed wetlands

Pollutant	Removal mechanism
Suspended solids	Impaction, filtration, settling, sorption and autoflocculation.
Biochemical oxygen demand	Sedimentation, degradation to CO_2, H_2O and NH_3 by microorganisms attached to plant and sediment surfaces.
Nitrogen	Nitrification and denitrification, NH_3 volatilization, sedimentation and plant uptake.
Phosphorus	Sedimentation, adsorption, complexation, precipitation reactions within bed matrix and plant uptake.
Heavy metals	Precipitation, sedimentation and adsorption onto biomass films on plant stems and bed matrix.
Pathogens	Sedimentation and filtration, competition and natural die-off, excretion of antibiotics from roots of plants and from composting of plant litter on bed surface.

(Gray and Biddlestone 1995)

All the three biodegradation process, namely, aerobic, anoxic and anaerobic are expected in the wetlands. The extend of each process depends on the process configuration, wastewater characteristics, plant species, temperature and other environmental conditions. BOD removal may be due to sedimentation and degradation by microorganisms attached to plant and sedimentation surface. According to Reddy and Angelo[30] in wetlands, BOD removed by settling of particulate BOD and breakdown of soluble BOD during microbial respiration. Organic matter in the wastewater, represented by BOD is removed in a reed bed mainly through aerobic biological decomposition by microorganisms growing in the matrix[12]. The availability of oxygen in the reed bed matrix is often assumed to be the key factor restricting the removal rates of BOD, COD and NH_4- N. Ciria et al.[8] reported that the BOD removal in wetlands is due to physical and biological processes that involve sedimentation and microbial degradation principally by aerobic bacteria attached to plant roots. Macrophytes by providing a suitable habitat for many decomposing microorganisms in the rhizosphere play an indirect but improvement role in reducing organic matter from various types of wastewater. The bed medium and the roots and rhizomes of the plants provide a large reactive surface on which bacterial growth is supported. The ability of the aquatic plants to transfer oxygen into the bed creates aerobic micro zones around the roots and anaerobic zones away from them[25].

The primary nitrogen removal mechanism from wastewater is nitrification-denitrification, the secondary removal mechanism include uptake by subsequent harvesting of plants, volatilization of ammonia and sedimentation. The principal removal mechanisms of phosphorus are plant uptake and subsequent harvesting and chemical and biochemical fixation in the sediments. Phytoplankton, floating macro algae and emergent macrophytes are important storage compartments contributing to pretention in wetlands. Due to its large surface area and short reproduction time finely dispersed phytoplankton is able to eliminate phosphorus efficiently from the water[20]. Many studies have demonstrated that subsurface flow of wastewater through beds of porous rooting media planted with aquatic macrophytes can result in effective removal of major inorganic pollutants from wastewater[31]. Oxygen diffusion from roots submerged in the wastewater is thought to facilitate the removal of organic C and mineral N by enhancing microbial processes at aerobic/anaerobic interfaces[21]. Artificial wetlands are known to offer a suitable combination of physical chemical and biological factors for removal of bacteria. Physical factors include mechanical filtration and sedimentation. Chemical factors include oxidation, exposure to biocide excreted by some plants and absorption to organic matter[1] biological removal mechanism include antibiosis[33], ingestion by nematodes and ciliates and natural die-off[14].

TREATMENT OF DIFFERENT TYPES OF WASTE WATER USING CONSTRUCTED WETLAND TECHNOLOGY

Constructed wetland technology is extensively used for treating variety of wastewater like, domestic wastewater, textile dye waste, anaerobic swine lagoon, piggery effluent, poultry lagoon effluent, and dairy farm waste. Many of the systems currently in use around the world have been designed to treat domestic wastewater and generally use the concepts originally given by Kickuth, operating in Germany since 1972. These involved horizontal subsurface flow through an inert porous medium planted with suitable aquatic plants such as *Phragmites australis*. Constructed wetlands have been very successful in treating municipal wastewater treatment, wetland systems are operated to meet extreme discharge requirements. Juwarkar et al.[24] studied the efficiency of constructed wetland, which consists of emergent macrophytes *Typha latifolia* and *Phragmites karca* grown in cement pipes having 0.1256 m^2 area and 0.8 m deep filled with 30% soil and 70% sand. It was found that the constructed wetland showed a significant removal of BOD (65-75%), nitrogen (30-50%) and phosphate (75-85%) from the domestic wastewater. Sub-surface horizontal flow constructed wetland with indigenous *Phragmites karka* covering an area of 41.8 m^2 was installed in 1997 for treatment of domestic wastewater at Vikram University, India. The system has been reported to perform well with BOD removal of 65%, TSS, 78%, NH4 –N, 78%, TP, 56–65. The effuent is reported to have a dissolved oxygen level of 34%[3]. The efficiency of constructed wetlands receiving primary treated domestic wastewater was studied by Coleman et al.[9] with three common Appalachian plant species (*Juncus effusus* L., *Scirpus validus* L., and *Typha latifolia* L.). The experimental design includes two wetland gravel depths (45 and 60 cm) and five planting treatments (each species in monoculture, an equal mixture of the three species, and controls without vegetation), with two replicates per depth x planting combination. The results showed a 70% reduction in total suspended solids and BOD, 50 to 60% reduction in nitrogen (TKN), ammonia and phosphate, and areduction of fecal coliforms by three orders of magnitude.

Performance of pilot-scale subsurface flow constructed wetland with 450 m^2 in landfill leachate treatment was monitored by Bulc et al.[7]. The results showed that the reduction of COD, BOD, NH_3-N, Fe and bacteria were 68, 46, 81, 80 and 85%, respectively achieved. *Eichhornia crassipes* would also remove silver from industrial wastewater for subsequent recovery with high efficiency in a short time[29]. Muramoto and Oki[28] reported that the *Eichhornia crassipes* is capable in bioaccumulation of heavy metals *viz*., Pb, Cr, Cu, Cd and Zn from contaminated water. Constructed wetlands have a potential for treating industrial effluents containing normally difficult organic molecules such as priority pollutants and dyes. Textile dyes create major water pollution, since it imparts colour to the water let out from the industries. Constructed wetland technology have the capability of 100 per cent dye reduction with 6 m travel through the bed by treating the pollutants like phenols, cresols by processes such as absorption and bacterial break down, chemical oxidation, adsorption on to the bed matrix and sedimentation[11]. Hill et al.[19] reported that the free water surface constructed wetland systems was used for the removal of COD, BOD, PO_4 and K from the poultry lagoon effluent with P*hragmites, Sagitarius, Scripus spp* etc.

CONCLUSION

Constructed wetlands are a viable alternative for wastewater treatment for reducing the organics and suspended solids with low-cost. The design should take into account the type of wastewater and the loading rate, the climatological setting of the designed wetland, the sediment and plant types to be used and the management needed for operation of the wetland.

REFERENCES

[1] A.Batchelor, W.E.Scott, A.Wood; Constructed Wetland Research Programme in South Africa. In: Constructed Wetlands in Water Pollution Control, P.F.Cooper, B.C.Findlater, (Eds); Pergamon Press, Oxford, 373-382 **(1990)**.

[2] H.J.Bavor, D.J.Rosser, S.A.Mckersie; Nutrient Removal using Shallow Lagoon, Solid Matrix Macrophyte System. In: Constructed Wetlands for Municipal, Industrial and Agricultural Waste Water Treatment. D.A.Hammer, (Ed); Lewis Publishers, Michigan, 646-656 **(1989)**.

[3] S.K.Billore, N.Singh, L.K.Sharma, P.Dass, R.M.Nelson; Wat.Sci.Tech., **40**, 163-171 **(1999)**.

[4] J.L.Bolis, T.R.Widleman, R.R.Cohen; The Use of Bench Scale Parameters for Preliminary Analysis of Metal Removal from Acid Mine Drainage by Wetlands. In: Proc.of the Conference of the American Society of Surface Mining and Reclamation, May 14 -17, Durango. Co., 123-136 **(1991)**.

[5] H.Brix; Wat.Sci.Tech., **29**, 71-78 **(1994)**.

[6] H.Brix, H.H.Schierup; Ambio, **18**, 100-107 **(1989)**.

[7] T.Bulc; D.Vrhovsek, V.Kukanja; Wat.Sci.Tech., **35(5)**, 301-306 **(1997)**.

[8] M.P.Ciria, M.L.Solano, P.Soriana; Biosystems Engng., **92(4)**, 535-544 **(2005)**.

[9] J.Coleman, K.Hench, K.Garbutt, A.Sexstone, G.Bissonnette, J.Skousen; Water, Air and Soil Pollution, **128**, 283-295 **(1997)**.

[10] R.W.Crites, C.C.Lekven, R.A.Beggs; Constructed Wetlands at Mesquites, Nevada. In: Proceedings of the ASCE Environmental Engineering Conference, 390-395 **(1994)**.

[11] T.H.Davies, P.D.Cottingham; Wat.Sci.Tech., **29**, 227-232 **(1994)**.

[12] EPA; Design Manual on Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment, EPA/625/1-88/022, 85-89 **(1988)**.

[13] R.M.Gersberg, B.V.Elkins, S.R.Lyon, C.R.Goldman; Wat.Res., **20**, 363-368 **(1986)**.

[14] R.M.Gersberg, S.R.Lyon, R.Brenner, B.V.Elkins; Appl.Environ.Microbiol., **53**, 731-736 **(1987)**.

[15] K.R.Gray, A.J.Biddlestone; TIBTECH, **13**, 248-252 **(1995)**.

[16] N.F.Gray; The Biology of Wastewater Treatment, Oxford University Press, New York, 98 **(1989)**.

[17] W.Grosse; Thermoosmotic Air Transport in Aquatic Plants Affecting Growth Activities and Oxygen Diffusion to Wetland Soils. In: Constructed Wetlands for Wastewater Treatment. D.A.Hammer, (Ed); Lewis Publishers, Michigan, 469-476 **(1989)**.

[18] R.S.Hedin; Treatment of Coal Mine Drainage with Constructed Wetlands. In: Wetland Ecology and Conservation– Emphasisin Pennsylvania. S.K.Majumdar, R.P.Brooks, F.J.Benner, R.W.Tine, (Eds); The Pennsylvania Academy of Science, 349-362 **(1989)**.

[19] D.T.Hill, J.W.Rogers, V.W.E.Payne, S.R.Known; Wat.Sci.Tech., **34**, 456-462 **(1996)**.

[20] C.Howard-Williams; Freshwater Biol., **15**, 391-431 **(1985)**.

[21] H.Iizumi, A.Hattori; J.Exp.Mar.Bio.Eco., **47**, 191-201 **(1980)**.

[22] A.Jensen, C.Nicolson, J.Carter; Restoration Techniques for Wetland Systems. A Case Study in the South Australian River Murray Valley. In: Proc.First International Lowland Stream Restoration Workshop Land, Sweden, 34-42 **(1991)**.

[23] P.D.Jensen; Wat.Sci.Tech., **28(10)**, 149-157 **(1993)**.

[24] A.S.Juwarkar, B.Oke, A.Juwarkar, S.M.Patnaik; Wat.Sci.Tech., **32(3)**, 291-294 **(1995)**.

[25] G.J.Lawson; Cultivating Needs (Phragmites australis) for Root Zone Treatment of Sewage. In: Contract Report ITE Project 965. Water Research Centre, Cumbria, UK, 72 **(1985)**.

[26] Metcalf, I.N.C.Eddy; Wastewater Engineering: Treatment, Disposal and Reuse. 3rd Edition, New York, McGraw-Hill Book, 1334 **(1991)**.

[27] S.L.Michand, C.J.Richardson; Relative Radial Oxygen Loss in Five Wetland Plants. In: Constructed Wetlands for Waste Water Treatment, D.A.Hammer, (Ed); Lewis Publishers, Michigan, 501-507 **(1989)**.

[28] S.Muramoto, Y.Oki; Bulletin of Environmental Contamination and Toxicology, **30**, 170-177 **(1983)**.

[29] C.L.R.Pinto, A.Caconia, M.M.Souza; Wat.Sci. Tech., **19(10)**, 89-101 **(1987)**.

[30] K.R.Reddy, E.M.D.Angelo; Wat.Sci.Tech., **35(5)**, 1-10 **(1997)**.

[31] K.R.Reddy, W.H.Smith; Aquatic Plants for Water Treatment and Resource Recovery. Magnolia Press, Inc., Orlando, FL, **(1987)**.

[32] K.Seidel; Macrophytes and Water Purification. In: Biological Control of Water Pollution, J.Toubier, R.W.Pierson Jr., (Eds); Univ. Pensylvania Press, USA, **(1976)**.

[33] K.Seidel, H.Happel, G.Graue; Contributions to Revitalization of Waters. Limnologishe Arbeitsgruppe, Max-Planck-Gesellschaft, 64 **(1978)**.

[34] G.Tchobanoglous, R.Eliassen; J.Sani.Div.ASCE, **96(2)**, 243-265 **(1970)**.

[35] J.Vymazal; Ecol.Eng., **25**, 478-490 **(2005)**.

[36] R.K.Wieder; Wetlands, **9**, 299-314 **(1989)**.