Decentralized Wastewater Treatment By Bio-Rack Wetland System: A Review

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Abstract-* *Wastewater generated from domestic establishments should be treated before disposal. Conventionally the wastewater treatment is provided in centralized manner. For the rural areas and isolated households the decentralized treatment system is beneficial due to low cost and low maintenance. Constructed wetlands are often used for decentralized wastewater treatment, however this system has limitations viz. requirement of larger area, clogging, and appropriate media to support wetland vegetation. Bio-rack wetland system which addresses these limitations has been tried successfully for treatment of domestic wastewater and low concentration polluted river water. This review paper presents detailed literature on Bio-rack wetland system and its use for wastewater treatment. Further, the constraints of conventionally used bio-rack system and possible modifications to improve the performance which include changing flow pattern, multispecies vegetation, and possibility of increasing attached growth surface area are also discussed.

Key words: Constructed wetlands, Bio-rack wetland, Decentralized wastewater treatment, Multispecies vegetation, Wastewater treatment

I. INTRODUCTION

Liquid waste is generated predominantly by domestic wastewater. The treatment of domestic wastewater by safe, economic and effective manner is one of the most challenging problems faced worldwide. In India hardly 10% of the sewage generated is treated effectively, while the rest of the sewage finds its way into natural ecosystems and being responsible for large-scale pollution of rivers and ground waters (Trivedy, 2001). Conventionally wastewater is treated in centralized treatment facility by Sequential Batch Reactors, Moving Bed Biological Reactor, and Activated Sludge Process. The large capital investment of sewerage system and pumping costs associated with centralized systems can be reduced, thus increasing the affordability of wastewater management systems (Massoud, 2008).In absence of sewer lines, decentralized treatment system can be cost effective and convenient.Such systems are less expensive to construct, simple to operate, requires less maintenance cost than centralized treatments.Presently in India, the decentralized treatment to wastewater is given by septic tank followed by soak pit.The water from soak pit ultimately reaches ground water and it can contaminate the same.

For single households, rural areas and city outskirts decentralized wastewater system is convenient treatment possible to meet the effluent discharge standards.Constructed wetland is an alternative option for secondary treatment of domestic wastewater at individual household level and also for the treatment of effluent from septic tank.Treatment in constructed wetlands is achieved by passage of wastewater through support media (gravel, grit, plastic media, alum sludge etc.) planted with vegetation. The combination of various constructed wetland systems can be adopted in a single unit to overcome the drawbacks of each system. The bio-rack wetland system is a potential system to treat the domestic wastewater by overcoming the limitations of conventional constructed wetlands.

II. LITERATURE REVIEW

Constructed wetlands have been used for domestic wastewater treatment since long time. Multispecies constructed wetlands have effective distribution of roots and hence better microbial population than single species (Sohair 2012, 2014). Various media have been used in constructed wetlands like gravel, alum sludge, plastic media, light weight aggregates, charcoal etc. Alum sludge is used as media which enhances phosphorus removal along with organic matter (Zhao 2008, Babatunde 2010). Hybrid arrangement consisting of series of horizontal flow followed by vertical flow constructed wetland has been tried for the treatment of domestic wastewater. The hybrid system showed better removal efficiency of organic matter and denitrification than separate system (Oovel 2007, Ayaz 2015, Cuong 2017)

Valipour *et. al* (2009) studied Bio-rack system for the treatment of domestic wastewater. The reactor consists of 30 PVC pipes of 50 mm diameter and 500 mm length arranged in a rectangular configuration. All the pipes had 20 mm perforations all over their surfaces. Pipes were planted with *phragmites species.* The bio-rack was operated at 18–6 h Hydraulic Retention Time (HRT) at an average BOD_5 loading of 15.11–47.98 (g/day). The efficiency of this system is due to better oxygen transfer through the root zone and higher microbial growth on the surface of bio-racks. By keeping similar reactor volume it was observed that performance of Bio-rack system was better than conventional system in terms of DO, COD, BOD_5, Chlorides, TDS, TSS, Nitrates and MPN. At optimum HRT of 10 h, approximately 75.15% COD, 86.59% BOD_5, 27.54% TDS, 73.13% TSS, 8.86% Chlorides, 70.22% NH_3-N, 31.71% PO_4-P and 92.11% MPN reduction was achieved in bio-rack system.

Valipour *et. al* (2011) studied potential of bio-rack system for treatment of domestic wastewater in the presence of high TDS and heavy metal salts. *Phragmites species* was planted in all the pipes. TDS content was maintained by addition of sodium chloride in domestic wastewater and heavy metals (Cd, Zn, Ni, and Cu) were introduced as salts. The results revealed that *phragmites species* can tolerate high TDS up to 9000 mg/lit. It also showed prolonged resistance to 40 mg/lit of heavy metals load.

Wang *et. al* (2011)compared efficiency of contaminant removal between four wetland plants species. Pilot scale study was conducted to evaluate the contaminant removal efficiency of four plant species namely *Thalia dealbata*, *Acorus calamus*, *Zizania latifolia* and *Iris sibirica.* The reactors consist of 20 PVC pipes with 90 mm diameter and 400 mm length with 20 mm perforations. Hydraulic loading during experiment was controlled at 0.24 $m^3/(m^2\cdot day)$. The four species of plants grew well in microcosm containers under the same culture conditions when loaded with simulated polluted river water, demonstrating that the quality of low-concentration polluted river water can meet the growing requirements of high-density plantings. The study indicated that over 50% of the TN and 60% of the TP were removed from the influent in the four bio-rack wetlands during the long-term operational period. It demonstrated the feasibility of bio-rack wetland to treat low-concentration polluted river water. The bio-rack planted with *T. dealbata*, accomplished better nutrient removal than those planted with the other species. Removal rates were 48.65%–78.07% for TN, 51.22%–68.96% for NH_3-N, and 77.4%–86.07% for TP in the *T. dealbata* system during the operational period.

Wang *et. al* (2012) studied treatment efficiencies of two plant species. *Thalia dealbata* and *Acorus calamus* are the cultured plants used to treat the low concentration river water. The reactor consists of 20 PVC pipes with 90 mm diameter and 400 mm length with numerous perforations of 20 mm diameter. Hydraulic loading rate was controlled at 0.24 $m^3/(m^2\cdot day)$. The average removal efficiencies of wetland planted with *Thalia dealbata* and *Acorus calamus* were 67.36% and 58.42% total nitrogen, 63.31% and 50.13% NH^3-N, 71.69% and 54.73% NO^3-N, 80.62% and 70.01% total phosphorus, and 24.03% and 19.19% COD respectively. Most of the aquatic macrophytes grew successfully while *Thalia dealbata* performed better than *Acorus gramineus* for contaminant removal.

Jamshidi *et. al* (2014) studied the potential use of Anaerobic Baffled Reactor (ABR) followed by Bio-rack wetland planted with *Phragmites sp.* and *Typha sp.* for treating domestic wastewater generated by small communities. The reactors consist of 15 vertical PVC pipes with 60 mm diameter and 500 mm length with 20 mm perforations. Two parallel laboratory-scale models showed that the process planted with *Phragmites sp.* and *Typha sp.* are capable of removing COD by 87% & 86%, SCOD by 90% & 88%, BOD_5 by 93% & 92%, TSS by 88% & 86%, TN by 79% & 77%, PO_4-P by 21% & 14% at an overall HRT of 21 and 27 hours, respectively. *Phragmites sp.* has adapted its root system to extend over the depth of the wetland unit, resulting in higher oxygen transfer efficiency through the roots, better nutrient uptake, and larger surface area for aerobic microbial biofilm to adhere and growth as compared to *Typha sp.*

Marchand *et. al* (2013) studied bio-rack system for treating Cu-contaminated freshwaters. Each pilot constructed wetland (CW, 110 dm^3) contained 15 perforated vertical pipes filled with a mixture of gravel (diorite; 80%) and perlite (20%) and assembled as a rack. All vertical pipes were perforated at every 5 cm in height and width (hole diameter: 5–10 mm). All macrophytes were well developed in the bio-rack system and provided a large root surface area for the growth of microbial populations in oxidative conditions.

III. CRITICAL ANALYSIS- DISCUSSION

The literature review showed that extensive research has been carried out on constructed wetland for domestic wastewater treatment. The studies include various arrangements, configurations and mode of operations. Various arrangements include changing flow pattern, baffled arrangement, configurations include hybrid and modes include batch and continuous operation. The hybrid arrangement includes multimedia or multispecies operation. Literature showed that the use of multispecies vegetation in a single reactor of constructed wetland gives better removal efficiencies and distribution of roots. The multispecies vegetation system has better root matrix than single species wetlands. Conventional constructed wetlands are susceptible to high suspended solids load. The clogging of media/substrate ultimately leads to reduction in hydraulic conductivity. The bio-rack system being free from media will not get much affected by the presence of suspended solids. Bio-rack wetland system is used for treatment of domestic wastewater and low concentration polluted river water. The system showed better removal efficiency than conventional constructed wetland of same volume. It has low capital cost, low space requirements and high organic degradation at lower hydraulic retention time than conventional constructed wetland. The available literature showed that the bio-rack wetland system has the potential to treat domestic wastewater. But there is some scope to modify the currently adopted bio-rack wetland system.

IV. POSSIBLE MODIFICATIONS TO ENHANCE PERFORMANCE OF CONVENTIONAL BIO-RACK SYSTEM

The present literature review showed that the modification to the bio-rack wetland system has not been tried. Currently adopted system can be modified in order to enhance the treatment efficiency of the currently adopted system. The various modifications can be made based on the modifications in constructed wetland. The improvement can be made based on the following aspects.

Altering flow pattern

The flow pattern in currently used bio-rack system is upflow. The flow can be altered by combining upflow and downflow arrangement. The alternate upflow-downflow arrangements can be made in a reactor. The use of alternate upflow-downflow will increase the contact time of wastewater in the reactor and more wastewater will come in contact with the roots which will possibly increase the treatment efficiency which is the dominant phenomena of treatment in the bio-rack wetland system. For circular reactors, wastewater can be centrally fed. During the passage to outermost chamber; wastewater will flow from series of concentric circles. The flow pattern can be made in series of upflow-downflow. Also use of baffles will lead to longer path for wastewater which will increase the contact area with the wastewater.

Use of Multispecies vegetation

The use of multispecies vegetation in conventional constructed wetland showed better treatment in many cases (Sohair 2012, 2014). The presence of diverse species in VFCW provided more effective distribution of the root system and a habitat for more diverse microbial populations and consequently better removal rates (So hair I., 2012). The same concept of using multispecies vegetation can be adopted for bio-rack wetlands as well. The multispecies plants have complex root structure. The different plants have varied root depth. So by combining different plants, the oxygen transfer zone of roots is at different heights. Hence the majority of reactor depth can be kept aerated using multispecies vascular plants. In multispecies arrangement, if different plants having varied root depth are used, it will lead to better oxygen transfer.

Use of Carrier media

Bio-rack wetland system performance is based on available attached growth surface area. Increased possible surface area will enhance the treatment efficiency. The carrier media used for MBBR can be used in the bio-rack pipes below the roots so as to increase the attached growth surface area for the growth of microorganisms. The immediate zone in the vicinity of the plant roots is aerobic due to the vascular plants. The developed carrier media which are already having active bio-film on the surface can function in aerobic zone. Use of carrier media in upflow arrangement will further improve its suspension. Apart from carrier media, charcoal can be placed in each pipe. Charcoal being lighter material will remain in suspension in the upflow chamber. It will also act as an adsorbent material for the removal of impurities and also will provide an additional surface area for the growth of microorganisms.

Hybrid Arrangement

Combination of constructed wetland and bio-rack can be used as a single reactor. The conventional wetland substrate/media can be used as the bottom portion above which bio-rack can be placed. The upflow direction in such compartments will further enhance the better distribution of wastewater along with attached growth surface area provided by the substrate/media.

Use of Artificial aeration

In the conventional constructed wetlands, it is seen that use of artificial aeration helps in increasing the treatment efficiency at a shorter retention time. Similar concept can be adopted for the bio-rack wetland system as well which will further improve the treatment efficiency.

Various arrangements and modifications can together be used in single reactor for better performance of system.

V. CONCLUSIONS

Decentralized wastewater treatment at low cost is needed for rural and city outskirts. The bio-rack wetland system has shown a great potential to treat the domestic wastewater at a higher loading rate and within lesser space requirement than the conventional constructed wetland. Clogging problem in constructed wetland will also be overcome by using bio-rack system. So it appears to be a feasible method for treatment of domestic wastewater. With some of the modifications like altering flow pattern, multispecies vegetation, use of carrier media, hybrid arrangement and artificial aeration further performance of the current system can be enhanced.

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