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A Review On Floating Treatment Wetlands: An Eco–Friendly Method For Wastewater Reclamation

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Abstract: In this scenario, the Floating Treatment Wetland system (FTWs) are effective, eco-friendly, natural, energy-saving, and economical way of wastewater treatment. FTWs is a constructed floating raft has macrophytesgrowing above water surface with their roots are hangingbelow without touching the sediment. The plant roots uptake the nutrients from the wastewater and use it for their growth and reproduction. Also, provides habitat for microbial colonies. The microbes also enhance the treatment process by the breakdown of organic pollutants to simple inorganic nutrients that will be further absorbed by the plants. Furthermore, plant roots entrap solid particles and maintain a hydraulic flow between roots and water below FTWs. In this review article, the structure and design of FTWs, the features and operational parameters of FTWs, the role of plants, mechanism of pollutant removal, the efficiency of FTWs in the removal of nutrients, organic+matter and heavy metals, FTWs status in India and finally the points to consider in installation and maintenance of FTWs are discussed.

Keywords: floating treatment wetlands, wastewater treatment, pollution, mechanism, installation, and maintenance.

1. INTRODUCTION

Nutrient contamination from untreated sewage, industrial wastes, and many other anthropogenic activities, deteriorating the water quality of freshwater bodies. Nutrients and contaminants loading cause eutrophication of rivers, lakes, and ponds (Imboden, 1974). It causes a rapid increase in plant growth and algal blooms as a result the depletion of dissolved oxygen occurs in water bodies that affect the survival and reproduction of fauna. All that needs is effective wastewater treatment to keep our water bodies breathing. The centralized wastewater treatment systems are often expensive to construct and often fail due to lack of maintenance (Dubey & Sahu, 2014). It needs an environment friendly, low cost,low maintenance, and highly efficient technology. The need for restoration of quality of water without further damaging nature gave the idea of simulation of this natural phenomenon.(Headley & Tanner, 2012)(Van De Moortel et al., 2010)(Rehman et al., 2019). Thus, Floating Treatment Wetlands (FTWs) were established as a hydroponic technology to treat wastewater systematically, feasibly, and cost-effectively ((Headley & Tanner, 2012),(Dubey & Sahu, 2014).This review gives insight into the structure and design of FTWs, the features and operational parameters of FTWs, the role of plants, plant-bacteria synergism in pollutant removal, mechanism of pollutant removal, the efficiency of FTWs in the removal of nutrients, organic matter, and trace metals. FTWs status in India and finally the points to be considered in the installation and maintenance of FTWs.

Floating Treatment Wetlands

FTWs are the treatment wetlands which are conceptually similar to natural wetlands excluding, their artificial floating raft which supports the growing macrophytes(Tanner et al., 2011). FTW is a system which is the combination of hydroponic planting technology and ecological engineering designed for wastewater reclamation in a sustainable, eco-friendly,long lasting, easy to maintain, and cost-effective manner (Rehman et al., 2019). The first term proposed by Fonder and Headley in 2010 to designate this system was" floating emergent macrophytes treatment wetland" but as the title was too long later on it was abbreviated to "floating treatment wetland "in 2012 by Headley and Tanner after that many aliases were used such as"constructed floating wetlands", floating treatment wetlands"," artificial floating Islands". Artificial floating Reed beds", the integrated floating system"," integrated ecological floating bed", floating mats", floating Islands" (Van duzer 2004);(Van De Moortel et al., 2010);(Billore et al., 2009);(Headley & Tanner, 2012);(Li et al., 2010)(C. Chen et al., 2013)(Rehman et al., 2019)

Structure

Structurally, the FTW system is composed of a floating raft with emergent macrophytes above the water surface and root zone below. The floating raft can be made from natural materials such as bamboos, coconut coir beds or man-made materials such as polyester sheets, PVC pipes, foam, floating frames which acts as a platform to fix and support the plants and enhance their growth (Billore et al., 2009)(Yao et al., 2011)(Shahid et al., 2018),(Z. Chen, Cuervo, et al., 2016)

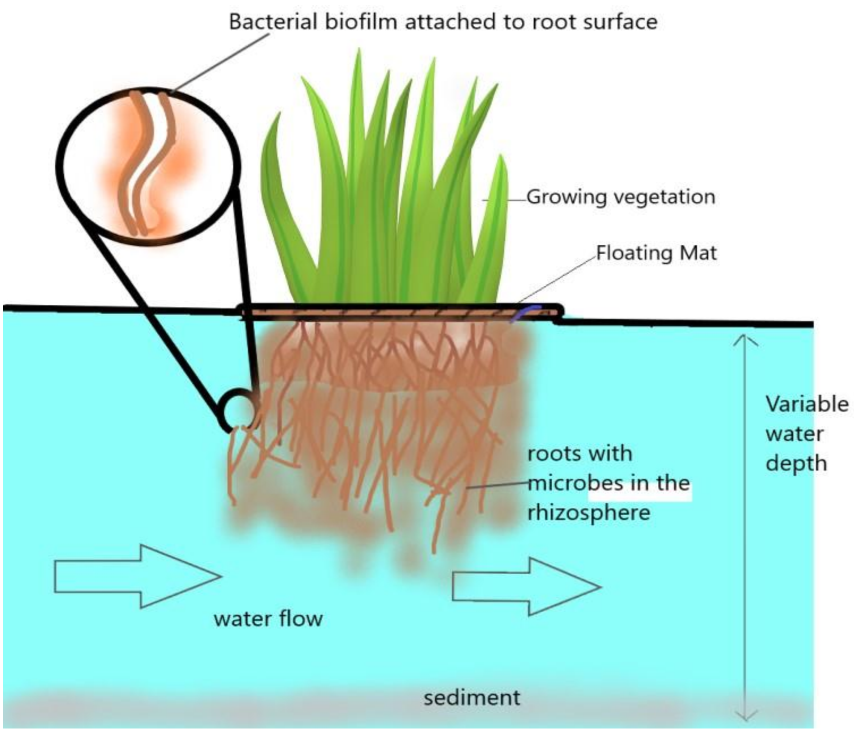

Figure 1: Schematic representation of floating treatment wetlands(FTWs) structure and pollutant removal process Adapted from:(Tanner et al., 2011).

Features and operational parameters

Vegetation and plant coverage

The selection of plant species for the FTW system relies on many factors such as type of wastewater, climate, species growth, the root type and growth in terms of length and surface area, aerenchymatous nature of roots, tolerance to high pollutant level, and ability to efficiently grow hydroponically (Headley & Tanner, 2012)(Rehman et al., 2019) ((Colares et al., 2020).

The fundamental characteristics for selection of a plant species for floating treatment wetland system are –1. Preferably, it should be native and non-invasive species, 2. Should be terrestrial and perennial in the habit, 3. Capable to form dense and submerged root network, 4. Should have aerenchymatous roots and rhizomes for high oxygen diffusion and to enhance their buoyancy potential, 5. Capable of adapting to harsh hydroponic conditions without showing symptoms of toxicity, 6. Should have the potential of high nutrient uptake(Wang et al., 2014);(Tanner et al., 2011); (Z. Chen, Cuervo, et al., 2016);(Colares et al., 2020); (Rehman et al., 2019).The most commonly used macrophytes in FTW systems belong to family Cyperaceae (e.g. *Carex fasicularis, Cyperus articulatus, C. papyrus, Schoenoplectus validus, Scirpus californicus, S. lacustris*),Poaceae (eg *Paspalum pennisetum, Phragmites australis*., *Vetiveria zizanioides*)and Typhaceae (eg. *Typha* sp., *T. dominguensis, T. latifolia,*).Studies showed that both terrestrial and halophytic plant species have the potential to use in FTWs. However, aquatic plants also performed very well and have their significance in wastewater treatment depending on the availability of plant species and type of treatment system. Terrestrial plant species have potential to develop huge network of root system which makes them suitable for uptake of contaminants but halophytes are a more suitable choice due to the presence of aerenchyma in their roots, (Shahid et al., 2018) ability of roots to transport oxygen to plant rhizosphere, (Stottmeister et al., 2003) ability to create redox potential gradient in the root zone, release sugar and organic acids along with secondary metabolites that help microbial communities in pollutant degradation (Jan Vymazal & Kröpfelová, 2009).

Macrophytes role in the treatment process

The above-ground part of macrophytes is involved in nutrient storage, provides insulation to the fauna of water body in winters, reducing wind velocity, reduces the risk of re-suspension of particulate matter,reduces the growth of algae by light attenuation, and give an aesthetic appearance to the water body. The plant part submerged in water is involved in uptake of nutrients, prevention of medium clogging in vertical flow systems, provide a surface for formation of microbial biofilms, entrapment of suspended particulate matter,release of root exudates and enzymes for the attraction of microbes (J Vymazal, 2008),(Rehman et al., 2019).

Buoyancy cum floating mat design

An artificial floating mat design is similar to the natural floating mat which is built naturally without any supporting structure and floats on the surface of the water by their inter-wined roots, rhizome, organic matter, and plant litter that forms a natural floating mat (Shahid et al., 2019). FTWs should be designed such as the root biofilm network remains in maximum contact with polluted water and not touching the bottom of the pond. Principal aspects considered during designing of an FTW are the buoyancy, durability, functionality, size, weight, environmental sensitivity, depth of water being treated, anchoring, flexibility, and its cost ((Headley & Tanner, 2012), (Z. Chen, Cuervo, et al., 2016)(Shahid et al., 2019). The floatable raft with different buoyant materials such as PVC pipes, bamboos, polyurethanes, polyester sheets has been used in different experiments. The material choice for FTWs construction decides the cost, durability, strength, longevity, and effectiveness to withstand changes in environmental conditions (Colares et al., 2020).

The type of vegetation i.e. macrophytes with aerenchymatous abilities are preferred since it makes the raft to float efficiently with increasing shoot length. Halophytes and emergent aquatic macrophytes have been most commonly used. The design engineering parameters also depend on purpose of treatment and wastewater to be treated. If wastewater with a higher percentage of fine particles, the FTWs of larger size with lower depth are preferred as it establishes a dense root system which acts as a filter for fine particulate matter while for the treatment of wastewater with coarse suspended solid particles, FTWs should have a free zone with loosely arranged root network which allows water to move freely through it promoting coagulation of bigger particles along with degradation of pollutants since best free water zone act as a laminar flow ((Headley & Tanner, 2012); (Rehman et al., 2019). Nevertheless,the area covered by macrophytes and density of plants on a floating raft are also important factors. The recommended surface coverage should be less than 50% of mat surface since by the end of the growing season 80% of mat area will be covered by vegetation (Colares et al., 2020).

Hydraulic retention time (HRT)

The hydraulic retention time is a measure of an average length of time holding the wastewater in a treatment system unit either in the field or in the laboratory. The HRT value in the FTWs researches have been done to date ranging from few hours to several days such as a minimum of 2.1 h (Kussin et al.2019), one day((Gao et al., 2017)), 2 days, and 7 days ((Abed et al., 2019), 22 days ((Van De Moortel et al., 2010),49 days (Effendi et al.2017), 6 months ((Billore et al., 2009), 540 Days ((Shahid et al., 2019). with an increase in HRT the BOD, turbidity. TSS, COD, and NO3-N decrease while the amount of dissolved oxygen and ammonium nitrogen NH4 –N., sedimentation increases but a short HRT period 2 to 7 days increases BOD than control which is without macrophytes. Gonzales et al.recommended a minimum HRT of 5 days. In their studies, when the HRT was reduced from 14 to 7 days, there were no significant changes in the results.

Ghosh and Gopal 2010 conducted a study on HRT effect on the tertiary treatment of wastewater with *Typha angustata*. They kept the HRT of 1, 2,3,4 days the HRT of 4 days showing maximum results that is 90% of nitrate nitrogen and TKN, 100% of NH4-N removal, and significant removal of BOD and COD (Ghosh & Gopal, 2010). In another study, the HRT of 4 days was found to be essential for meeting the desired bathing standard for fecal coliforms and N removal while substantial P removal requires a higher HRT of at least 15 days (Toet et al., 2005).

Mechanism of pollutant removal

In FTWs wastewater reclamation occurs by various physico-chemical, and biological processes. The important processes involved in contaminant removal in FTWs are contaminants settling and binding in sediment pool, uptake of nutrients (nitrogen and phosphorus) and heavy metal ions by plants, release of root exudates and extracellular enzymes from plant roots, development of microorganisms biofilm on the root surface, enhancement of anaerobic conditions in the water column beneath the floating mat.

Removal of dissolved and suspended solids

Total dissolved solids (TDS) is the conductivity and salinity of the water. Similarly, total suspended solids(TSS) show the nitrates, phosphates, carbonates, and bicarbonates of K, Na, Mg and Ca salts, organic matter and, other particles. TSS are predominantly eliminated by physical settling, plants uptake and filtration process of FTWs(Wei et al., 2020)(E. Borne et al., n.d.). From studies, it has been found TDS and TSS of water shows a significant decline on the inclusion of FTWs (Prajapati et al., 2017)(Nichols et al., 2016)(Tanner, 1996). The plant root network plays a crucial role in the entrapment, filtration, and sedimentation of suspended solids and pollutants(Tanner et al., 2011).

Removal of nutrients by FTWs

The Major nutrients of wastewater are nitrogen and phosphorus. Plants uptake nitrogen as nitrates, microbes convert ammonium nitrogen to nitrate by nitrification process.(Z. Chen, Cuervo, et al., 2016)(Zhang et al., 2016). From studies it has been found that 61% of total nitrogen is removed by microbes, 14 % uptake by plants, 25% is retained in water being treated with FTWs(Rehman et al., 2019). Therefore, bacteria enhances the removal of nitrogen along with plants by their enzymatic actions. Studies revealed that the mechanism involved in phosphorous removal is sorption of dissolved phosphorus, physical entrapment of phosphorus in roots, and settlement (K. E. Borne, 2014). A field trial for Phosphorus removal with FTWs was carried out at Auckland, New Zealand in the stormwater retention pond. They found a 27% decrease in phosphorus in the outlet (K. E. Borne, 2014) . Chang et al. in 2013 reported that 47.7 percent of total phosphorus and 79% of orthophosphate removal from stormwater retention pond using *Juncus effusus.* In the comparative study of different plant species, they found that *Juncus effusus* more efficiently uptake nutrients than *Pontederia cordata* (77 .0 g N, 8.8g P removal) (Chang et al., 2013).Ge et al. in 2016 studied the effect of seasonal changes on nutrient removal and harvesting strategy using three plant species *Canna Indica, Thalia dealbata*, and *Lythrum salicaria*. Among all these *Thalia dealbata* exhibited the best seasonal applicability and best nutrient removal efficiency. TN removal is 69.96% +2.11%, TP removal is 82.4% +2.34% (Ge et al., 2016).Another comparative study on nutrient uptake using plant species *Iris pseudocorus* and *Typha angustifolia* was conducted. *Iris* showed free total nitrogen and total Phosphorus removal rate higher than *Typha* i.e. TN 74% and TP 60%(Keizer-Vlek et al., 2014) For Phosphorus removal use of pelletilized ochre cement pellets was also done, results showed improved the performance of FTW in phosphorous removal ((Abed et al., 2019).

Removal of heavy metal ions

Heavy metal ions are removed by the process of their binding with soil and sediments, precipitation and uptake by microbes and plants (Kadlec &Wallace 2009), and formation of metal sulfides (Rezania et al., 2016). The removal of toxic metal ions is stimulated by root exudates that help in forming metal sulfides and hydroxides (*Dodkins-Report. 2018 0n Efficiency of FTW*, n.d.)

Huang et al. in 2017conducted a study on the removal of heavy metals Cu, Zn, Pb, Cr from Yangtze estuary.The maximum Pb concentration value in the roots (24.54 mg/kg) was observed, Zn concentration in above-ground plant tissues was 66 mg /Kg, highest Cu concentration 27.84mg /Kg found in rhizome in summer and 149.58 mg Cr /Kg in the roots. It was concluded that roots are the main site of heavy metal accumulation that are good for phytoremediation.(Huang et al., 2017). From some other studies, it was also found that plants aggregate and immobilize metals in their root tissues. Thus, limiting metal toxicity in the above ground parts (Bragato et al., 2006)(Wei et al., 2020).

Indian status of FTWS for wastewater reclamation

Billore et al in 2009 conducted a study using *Phragmites australis* using an experimental mesocosm at river Kshipra. The results showed 55–60% of TS, 45–55% of NH4-N, 33–45% of NO3-N, 45–50% of TKN, and 40–50% of BOD removal (Billore et al., 2009).

Introduction of the largest floating island with 3500 saplings for the revival of Neknampur lake of Hyderabad by an NGO Dhruvansh have remarkably improved the quality of water by absorption of a high content of nitrogen and phosphorus in the lake(the Hindu, Feb 03, 2018). The FTWs were installed close to the entry point of wastewater with three different layers of cleaning, first layer is of floating aquatic weed, the second layer is of *Typha* and *Phragmites*. After passing through these layers dirty water gets cleaned enough for the survival of fishes and other aquatic animals. Dhruvansh NGO has been awarded in December 2019 for saving and rejuvenating Neknampur lake (The Hindu, 20 December 2019). In 2018, the Delhi government took the initiative to control water pollution in Delhi Rajkori lake by introducing FTW and given the name floating purification Iceland(Times of India, December 28, 2018).

Implementation and maintenance of FTWS

1. Tall plants should be avoided since they can cause sailing, drifting, or sinking of FTWs under high wind currents. **2.** Deciduous plants with large aboveground biomass loss should be avoided as it releases accumulated pollutants further in the water column. **3**.Plants with dense and fibrous root system should be preferred since it provides a large surface area for biofilm formation. **4.** Plant species tolerant to high pollutant load and anaerobic conditions should be preferred. **5.** All aquatic weeds should be removed before installation and regular monitoring should be done to prevent their proliferation in pond and FTW. Regular pulling of weeds should be done from FTW.**6.** Netting or plastic grids should be used to cover at initial stages to prevent damage of saplings from feeding by birds or animals (K. E. Borne et al., n.d.).

2. CONCLUSION

In developing countries such as India, FTWs are cost-effective means of wastewater reclamation. It is a good example of eco-engineering technology for treating wastewater. Important aspects to be considered during installation of FTWs includes durability, strength a floating raft, its ability to provide space for growing plant roots, withstand fluctuating water currents. Plant vegetation should be capable to grow and uptake the nutrients without showing signs of toxicity. Harvesting and removal of sediment should be done when required for greater functioning of FTWs.The detailed mechanism of pollutant removal by plants and microbes is topic of future research. Plastic waste products and other packaging waste products should be used for the construction of rafts to make it minimize its cost to zero. More number of native plant species should be explored. Furthermore, the harvested vegetation use for biofuel production or in any other use is the area of research.

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