TREATMENT OF GREY WATER BY HYDROPONIC TECHNIQUE

D. Saranya[1], M. Sabhari[2]

[1]*PG Scholar, Erode Sengunthar Engineering College, Perundurai, Tamilnadu, India*
[2]*Assistant Professor, Department of Civil Engineering, Erode Sengunthar Engineering College, Perundurai, Tamilnadu, India*

Abstract - *The present study was carried out in textile industries, to treat the canteen wastewater using hydroponics technique as a recycling method. Textile industry is located in Karaipudur which is situated in the palladam taluk of Tirupur which houses more than 3 factories and thus lack of water supply from the corporation. It hosts around 1600 peoples in diverse departments. The average wastewater generated in the canteen is approximately 213.8 liter per day in which it is then allowed for settling in a tank. Thus, this paper hypothesis a cost effective method to remove the pollutants present in the wastewater. This project report deals with the efficient plant based treatment system using aquatic plants occur in water bodies to remove the impurities present in canteen wastewater. BOD, COD, SS, nitrogen, phosphorus, metals and other elements, refractory organics, Other pollutant removal mechanisms which are analyzed using hydroponic technique, which defines the growing of plants in a liquid culture. In my project I use the A.Sessilis, Water hyacinth for treatment of grey water using hydroponic technique. The treatment unit has a capacity of reduction in 41% of EC, 52% of COD, 57% of TS, 38% of TDS, 57% of TSS, 45% of BOD, 69% of TKN.*

Key Words: Hydroponic Technique, Water Hyacinth, A.Sessilis, Grey Water.

1. INTRODUCTION

Tirupur is a city with exponential industrial growth in Tamil Nadu. With the increase in industrial population such as textile, it consequently consumes large volume of water. However, there has been declination in water source due to climate change and over consumption of surface and ground water. The people not only deplete the water source, but also pollute it through discharge of effluents into rivers without proper treatment. Though mitigation measures are taken to eliminate this problem, they are not enforced accordingly. Thus, there is need for recycle of wastewater from industries using feasible methods at system level. To save these sources of water from dwindling its mandatory to curb the over usage of it. There are many conventional methods for the treatment of these generated wastewater like activated sludge process, aerated lagoons, trickling filter and rotating biological contactor. But these methods are very expensive, complex and energy intensive. The factory should go in for decentralized, appropriate sustainable simple, less energy intensive treatment system for efficient management of the wastewater. There is growing demand for green wastewater treatment systems, which uses natural resources like solar energy, green plants and micro-organisms as their energy and cleansing agents. Natural and constructed wetlands are very good examples of sustainable way for treatment of wastewater. Among the various options available for the wastewater treatment, the system which utilizes plants as treatment agents are among the cheapest and the cleanest. Plant based treatment system are gaining importance nowadays for treating various contaminated wastewaters. Aquatic plants occur in water bodies enriched either by natural processes or by nutrient-loading from urban and agricultural activities, or by both. Despite of their nuisance characteristics, aquatic plants when cultured in wastewaters can perform several functions, including assimilating and storing contaminants. R&D efforts to harness the ability of aquatic macrophytes, such as water hyacinth, duckweed, salvinia, typha to purify biodegradable wastewaters had begun during mid-1970s (Abbasi et al., 2003). At present there are pilot scale Aquatic macrophytes based treatment plants running successfully inside the campus to treat wastewater generated in the facility.

Types of Aquatic Macrophytes

Floating Macrophytes

These include both species which are rooted in the substrate, e.g. Nymphaea spp. And Nuphar spp.(Waterlilies),Potamogeton natans (Pondweed) and Hydrocotyle vulgaris (Pennyworth),and species which are freely floating on the water surface, e.g. Eichhornia crassipes (Water hyacinth), Pistia stratiotes (Water Lettuce) and Lemna spp. and Spirodella spp. (Duckweed). The freely floating species are highly diverse in form and habit, ranging from large plants with rosettes of aerial and/or floating leaves and well-developed submerged roots (e.g.Eichhornia,Trapa, Hydrocharis), to minute surface-floating plants with few or no roots (e.g. Lemnaceae, Azolla, Salvinia).

Submerged Macrophytes

These have their photosynthetic tissue entirely submerged but usually the flowers exposed to the atmosphere. Two types of submerged aquatic are usually recognised: the elodeid type (e.g. Elodea, Myriophyllum, Ceratophyllum), and the isoetid (rosette) type (e.g. Isoetes, Littorella, Lobelia).

Emergent Macrophytes

These are the dominating life form in wetlands and marshes, growing within a water table range from 50 cm below the soil surface to a water depth of 150 cm or more. In general they produce aerial stems and leaves and an extensive root and rhizome-system. The plants are morphologically adapted to growing in water- logged or submersed substrate by virtue of large internal air spaces for transportation of oxygen to roots and rhizomes. This life form comprise species like Phragmites australis (Common Reed), Glyceria spp (Mannagrasses), Eleocharis spp. (Spikerushes), Typha spp. (Cattails), Scirpus spp. (Bulrushes), Iris spp. (Blue and Yellow Flags) and Zizania aquatic (Wild Rice).

2. METHODOLOGY

The canteen wastewater mainly consists of food particles, oil and grease, starch water, wash water and cleansing agents. It generates 213.8 l/day of wastewater.

Screening: The effluent is allowed to pass through initial screening with mesh size of 0.5mm diameter in order to screen the larger food particles. The solid waste is then collected manually.

Primary Sedimentation: Grey water is followed by settling tank of capacity 40 liters. The settling tank is lodged with jute bag to filter out the settle able suspended solids in the water. The remaining water with residence time allows the settling of residual solids to remove the BOD to some extent.

Secondary Sedimentation: A secondary settling tank following primary settling tank aids at removing more solids present in the influent water. The secondary settling tank can hold 40 liters of water in which it is equipped with 0.5 mm diameter mesh at the outlet of the tank. This is done to equalize the flow rate of the water in to a filtration unit.

Filtration: The filtration unit consists of sand and gravel media in which the suspended and colloidal particles are removed further. Additionally, the sludge from the treatment units are removed and washed through a drain valve below the ground surface that connects to a ditch nearby the unit operations. The water consequently flows to the reactor where the water hyacinth is allowed to float. Further treatment of the water to remove ions is done in the reactor such that the plant utilizes the minerals as its growth nutrients; removes the pollutants in the water and treats it.

3. Design of Existing Hydroponic Treatment

Plant:

The wastewater from the canteen is directly allowed to settle in a settling tank without prior and later treatments. The color and odour pose serious problems to aesthetics of the area. Thus, modification is done treat it using the Hydroponic Treatment System. The design was done based on the flow rate and the physico - chemical parameters measured at the inlet of the reactor. The average flow rate was measured to be 0.908 l/hr. and the COD was 900mg/l based on these data a Hydroponic Treatment System facility was set up. It was designed with a zigzag pattern of water flow with 3 flow channels of dimension 2.8 m x 0.4 m x 0.16 m (length x width x depth). Water Hyacinth, A.Sessilis, an aquatic free floating plant was used for treating the effluent. The design parameter of the existing system is shown in the table 3.1 and the features of existing site are shown in figure 3.1.

Fig 3.1 Features of Existing Site

Table 1 Design parameters of the existing Hydroponic Treatment System at canteen

HRT	4.8 Hrs
Flow rate	213.8 l/day
Total number of Channels	3
Volume of	0.179 m^3
Dimension of Channel	2.8m x 0.4 m x0.16m(LxBxH) x 3 channels

Problems encountered in the current system

The current site was designed based on the flow rate measured at the inlet of the first settling tank. The average flow rate in the canteen site was measured to be 213.8 l/day.

There was no settling taking place in the existing manholes and hence there was an entry of all settable solids in to the system and hence has ceased the survival of the plants due to excessive load and the entire trench was filled with floating solid sludge up to 5 cm deep. The site was not equipped with any oil & grease removal mechanism and hence there was an entry of oil and grease in to the system which was the major issue and has also contributed to the death of the plants figure 3.2.The baffles were very week as It's made of loose soil and there was a chance of breakage with would have disrupted the treatment system. The outlet of the system was not properly designed. The water was diverted to nearby land .but the topography was very steep

for the water to run and hence there was back flow of the water in to the system.

Fig 3.2 Problems encountered in Existing System

Materials Used In Hydroponic Reactor

The depth of the water level is 16 cm plants with roots growing up to that length and more were choose for the treatment. Two such deep rooted plants Water hyacinth were tried as they were easily available. The plants were collected from Sam Coimbatore. Since the plants were taken from fresh water it took two week for the plant to acclimatize to the canteen wastewater. The plant collection is shown in the figure 3.3

Fig 3.3 Plant Collection from Samalapuram, Coimbatore

Studies Done On Oil Removal capabilities

There is an entry of oil and grease into the treatment system. In the current site there was no set up for the removal of oil and grease. There are many options for the r and A.Sessilis

Samalapuram, ction 3.3. e removal of oil and grease like solvent extraction, flotraps, skimmers etc. But all these are costly and we have to go in for economically and technically feasible methods. Researchers have shown that several biomasses like Kapok fiber, cattail fiber, Water hyacinth, wood chip, rice husk, coconut husk, and bagasse can be used as sorbents for the oil and grease removal. The following methods were tried in lab scale to remove oil and grease from canteen wastewater in a cheaper and eco-friendly ways.

Using Dry Biomass of Water hyacinth,

A.Sessilis

hyacinth, A.Sessilis Hydroponic Treatment System .It was initially washed to remove mud or the other impurities. It was sun dried for 2 days and the dried biomass was slightly crushed and packed in a transparent polythene bag. Holes were made at the bottom of the bag to drain the filtered water.1 liter of the freshly collected wastewater was poured slowly over the top of the dried biomass .The filtered wastewater was collected in to a small bucket for oil and grease measurement. But the oil and grease removal was unsatisfactory using dried biomass of Water hyacinth, A.Sessilis. Water hyacinth, A.Sessilis requires constant replacement of the dried biomass once it becomes saturated and hence there should be easy availability of the plant in nearby locality. To have a better removal the biomass should be packed well and hence high quantum of pressure is required to push the water over the tightly packed biomass.

Using Rice Husk

rise husk was taken and washed in normal water to remove impurities. Then it was put inside a one liter plastic bottle. One liter of the canteen wastewater floatation, using A.Sessilis,

Sessilis: Biomass of Water , was brought from the arent d Usage of dry biomass of for oil removal

g Husk: A few grams of water was poured in to it and it was shaken well to bring good contact between the oil containing wastewater for 15 min. The bottle was kept undisturbed. The rise husk floated on the top and the water was filtered. The oil removal was not significant enough to quantify.

Using Jute Bags: Usage of jute bags for the oil and grease removal was very successful in lab scale. It was implemented in the site along with the fabricated filtration unit. Jute cloth was used as the last screen for the removal of oil was good but it needed constant replacement of the jute cloth. Within two days it got saturated and was replaced.

Method adopted on-site: From the above studies it is conclude that, though these methods are successful in lab scale and are environmental friendly and simple they require

large area for implementation practically. So it could not be implemented in the current site due to lack of space. The best option is to skim the oil using a skimmer. With this idea in mind a wooden plank was placed as a baffle at the end of first

trench with a small gap at the bottom to allow only the water to flow in to the next trench. This was found to be successful with no oil entry into the second and third trenches. It has been shown in figure 3.4.

Fig 3.4 Oil retaining wooden baffle

Removal of Suspended matter

The canteen wastewater is composed of food waste including vegetable waste, chilies, fine food waste, oil and grease, starch water, wash water and cleansing agents. The settable solids can be removed from the wastewater by considering these constraints a three layered screen setup was fabricated that could be placed at the end of the tank. Due to lack of availability of space, it was placed inside the settling tank. The fabricated filter is shown in the figure 3.5.

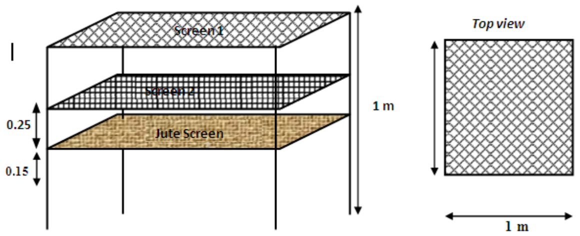

Fig 3.5 Design details of the fabricated

filtration unit

The screen setup consists of an outer screen frame of dimension 1 m X 1 m X 1.5 m and three screens. The entire setup is made up of wood. The screens can be easily removed for unloading the food waste and also the individual screen can also be replaced once it becomes rusted or clogged. The screen got clogged in two days and the last screen which was ade up of jute cloth got clogged immediately in two h ours and the was over flow and the entire system got disrupted.

An alternative was to change the location of the filtration setup to make it easily accessible for cleaning. The best option was to place the screens in the first trench. The first trench was thus used as a pre-treatment system with the screens placed 1 m apart. The first screen was a coarse screen to filter out large sized particles followed by a fine screen to remove other solid matters that may have escaped through the first screen.

Plant Layout and Design Details

The length and width of the site were not altered. The main idea was to check the efficiency of the Hydroponic Treatment System reactor without altering the dimensions of the site. The depth of the trench was increased to have a free fall of the wastewater into the trench. The first trench was used as a pre-treatment trench where the coarse and fine screens are placed to remove the settle able particles. To prevent the oil from entering a wooden plank was placed as a baffle at the end of the first trench. The treated outlet is diverted in to the already existing pond in to which the canteen wastewater was let into without treatment. The pond has been deepened to hold more quantum of treated water. The design parameters are shown in the table 3.2.

Table 3.2. Design parameters of the improved site

HRT	4.8 hrs
Flow rate	213.8 l/day
Total Number of Trench	3
Volume of 1 Channel	0.179 m^3
Depth of the trench	0.16 m
Dimensions of the Channel	2.8 m x 0.4 m x 0.16m (L x B x H)x 3 channels
Depth of water Level	0.16 m

Economic Aspect

The capital cost incurred in setting up the site is discussed below in the table 3.3.From the below table it's proved that Hydroponic Treatment System based treatment system is a cost effective treatment system.

Table 3.3 The overall expenditure & total cost of the project

Materials	Cost in Rs.
HDPE sheet	1000
Screen	250
Pipe accessories	2500
Super Bond	60
Labour Cost	4350
Total Cost	**8,160**

4. RESULTS AND DISCUSSION

Physico-Chemical Analysis

In this study Grey water samples were collected from hydroponic reactor and have been analyzed for some Physicochemical parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), Chemical oxygen Demand (COD), Biological Oxygen Demand(BOD), Total Kjeldahal Nitrogen(TKN). The result showed that pH, EC, TDS, TSS, TS, COD, BOD, TKN are discussed below.

Electrical Conductivity (EC): The EC was measured using digital EC meter after standardization. The results and performance is shown in the figure 4.1. The average reduction efficiency was 41 %.

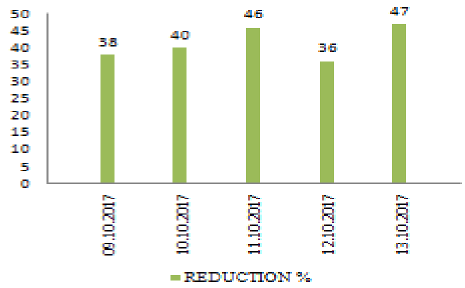

Fig 4.1 Reduction in EC pH:

The average inlet pH was 4.4 which indicate the canteen wastewater is acidic. The pH values recorded are shown in figure 4.2.

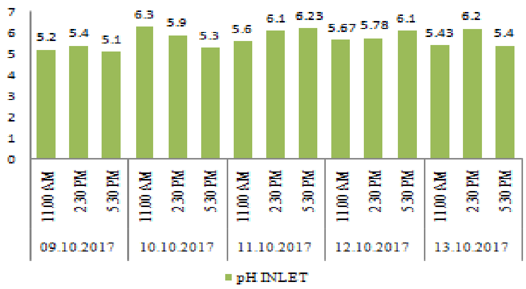

Fig 4.2 pH variation in Inlet

Chemical Oxygen Demand (COD):

The average inlet COD was 603 mg/l. The average COD removal efficiency was 52 % which was quite satisfactory. The performance of hydroponic treatment system in terms of COD removal shown in figure 4.3.

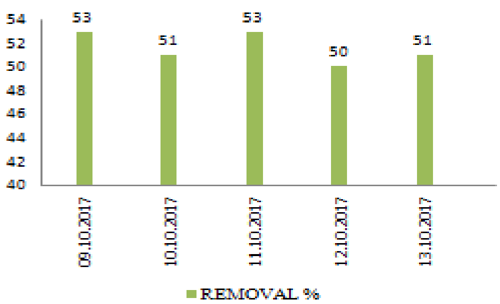

Fig 4.3 Reduction in COD

Total Solids (TS): The results are shown in the figure 4.4.The average inlet TS was 711 mg/l and the average removal efficiency was 57%.

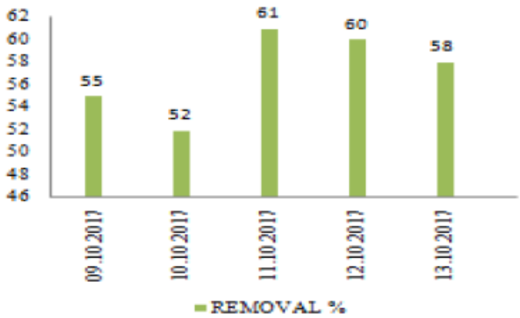

Fig 4.4 Reduction in TS

Total Dissolved Solids (TDS): The results are shown in the figure 4.5.The average inlet TDS was 443 mg/l and the average removal efficiency after treatment was 37 %.

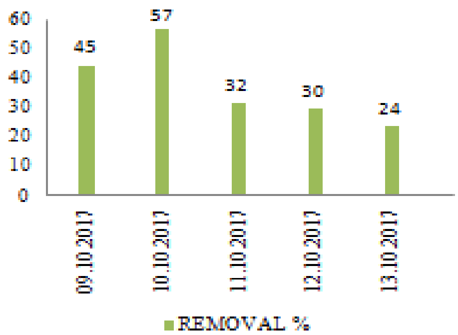

Fig 4.5 Reduction in TDS

Total Suspended Solids (TSS):

The results are shown in figure 4.6.The average inlet TSS was 265 mg/l and the average removal efficiency after treatment was 57%.

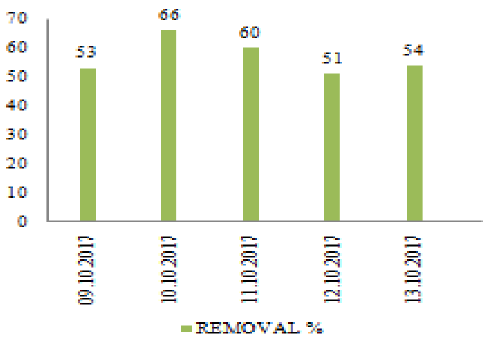

Fig 4.6 Reduction in TSS

Biochemical Oxygen Demand

(BOD): The sample was analyzed for three day .The results are shown in the figure 4.7.The average inlet BOD was 324 mg/l and the average removal efficiency was 45%.

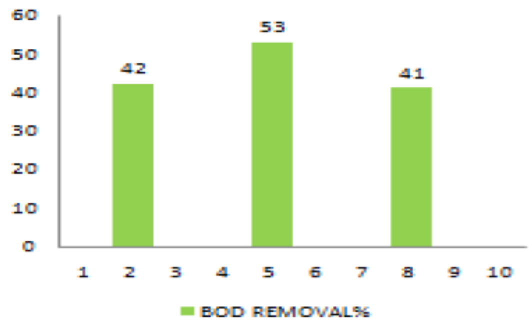

Fig 4.7 Reduction in BOD

Total Kjeldahal Nitrogen (TKN):

The experimental results are shown in the figure 4.8.The average inlet BOD was 21.3 mg/l and the average removal efficiency was 69%.

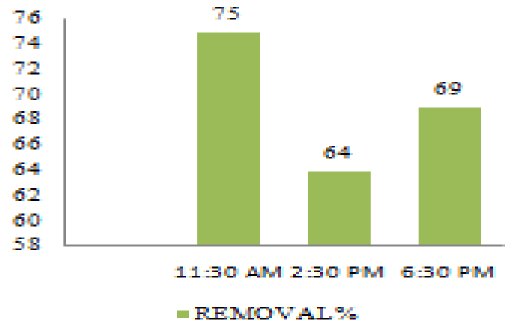

Fig 4.8 Reduction in TKN

Overall performance of the treatment unit on day basis

The overall performance of hydroponic treatment system from 09.10.2017 to 13.10.2017 was tabulated in the table 4.9. And the overall performance of treatment system has shown in fig 4.9.

Table 4.9 Overall performance of the treatment unit on day basis

DATE	% REMOVAL				
	COD	TS	TSS	TDS	EC
09.10.2017	53	47	53	45	38
10.10.2017	51	52	66	57	40
11.10.2017	53	61	60	32	46
12.10.2017	50	60	51	30	36
13.10.2017	51	58	54	24	47

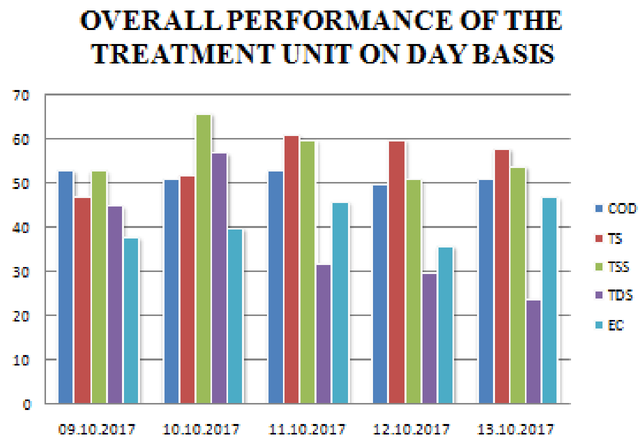

Fig 4.9 Overall performance of the treatment unit on day basis

5. CONCLUSIONS

Hydroponic Treatment System based wastewater treatment system of 2.8mX 0.4m X 0.16 m (length X width X depth) dimension with 4.8 hours HRT was constructed at the premise of the canteen to treat the discharged wastewater.

The challenge in this study was to tackle the problems that led to the failure of the previous unit and improvise the treatment efficiency of the existing system by modifying the design to handle entry of food particles, oil and grease in to the treatment unit. Fine and coarse screens were fabricated to prevent the entry of food particles. The oil and grease were retained using a wooden baffle and were skimmed off manually.

- The EC of the raw canteen wastewater was in the range of 413 µmhos/cm to 679 µmhos/cm. The average was 560.7 µmhos/cm. The peak value was at 11:00 am. The average drop in EC was 41% and the maximum removal was at 2:30 pm.
- The wastewater was acidic having an average inlet pH value of 5.7 and the outlet pH value of 5.5.
- The COD was in the range of 424 mg/l to 789 mg/l. The average was 603 mg/l. Higher value of COD is due to the oil & grease in the canteen wastewater. The average removal efficiency was 52%.
- The TS was in the range of 472 mg/l to 995 mg/l. The average was 711 mg/l. The average removal efficiency was 57 %.
- The TDS was in the range of 298 mg/l to 570 mg/l. The average value was 443 mg/l. The average removal efficiency was 38 %.

• The TSS was in the range of 147 mg/l to 420 mg/l. The average value was 265 mg/l. The average removal efficiency was 57%.

• The BOD was in the range of 280 mg/l to 375 mg/l. The average value was 324 mg/l. The average removal efficiency was 45 %.

• The Total Kjeldahal nitrogen was in the range of 20.5 mg/l to 22.4 mg/l. The average value was 21.3 mg/l. The removal efficiency was 69 %.

• The capital cost involved for the construction, operation and maintenance and the labour cost was about Rs.8,160 thus, proving the cost effectiveness of the treatment system.

From the above results and from the economic aspects discussed, modified Hydroponic Treatment System has proved to be an efficient, low cost, economically important system suitable for small communities for treating the domestic wastewaters. The treatment efficiency can be still increased to more than 90% by increasing the HRT of the reactor by adding on additional trenches to the existing modified system and by trying out with different plant species. The cost of the project can be still optimized. The food wastes filtered and settled at the bottom of the trench and the harvested plant biomass can be tried for composting or vermin composting and used as manure.

REFERENCES

[1] Abbasi, T. and Abbasi, S.A. (2010) Factors which facilitate wastewater treatment by aquatic weeds – the mechanism of the weeds_ purifying action. International journal of environmental studies, Vol 67, No. 3, PP.349 – 371.

[2] Abbasi, T. Abbasi, S.A., Ramesh, N., (2003). Mechanism of pollutant removal from waste water by aquatic macrophyte, Indian chem.engg., section B,45(3).

[3] Abbasi,S.A., (1995).Wastewater treatment with aquatic plants (State of the Art Report No.1NCOH/SAR-10/95), National Institute of Hydrology, Roorkee; 50. 4.

[4] Abbasi, S.A., and Ramasamy, E., (1999). Biotechnological methods of pollution control, universities press (India) Ltd.3-5- 819, Hyderguda, Hyderabad.

[5] Angelakis (2001). Management of wastewater by natural treatment systems with emphasis on land-based systems, IN: Decentralised Sanitation and Reuse, "concepts, systems and implementation". P. Lens, G. Zeeman and G. Lettinga , IWA Publishing, London. 2002.

[6] Boyd, C. E. (1974) Utilization of Aquatic Plants. In Aquatic Vegetation and Its Use and Control, Mitchell, D. S. (Ed.); United Nations Educational, Scientific, and Cultural Organization: Paris, pp.107–115.

[7] Brix. H. (1987) The applicability of the wastewater treatment plant in othfresen as scientific documentation of the root zone method. Water, science and technology 19:pp.19 -24.

[8] Brix, H. and Schierup, H.H. (1989) The use of aquatic macrophytes in waterpollution control. Ambio 18, pp.100-107.

[9] Brix, H. (1994) Functions of macrophytes in constructed wetlands. Water, Science and Technology. 29, pp.71-78.

[10] Brix H (1997) Do macrophytes play a role in constructed treatment wetlands? Water Sci Techno 35:pp.11–17.

[11] Boyd,C.E.(1969).Vascular aquatic plants for mineral nutrient removal of inorganic nitrogen from aquatic sysyems.J.Environ.Qual.3:pp.107-114

[12] Batchelor, A., Scott, W., Wood,A. (1990). Constructed Wetlands research program in South Africa. In: Cooper, P., Findlater, B. (Eds.), Constructed Wetlands in Water Pollution Control. Pergamon Press, Oxford.

[13] L.R. Buddhavarapu, and S.J. Hancock (1991), "Advanced treatment for lagoons using duckweed". J. Water Environ. Technol, vol. 3, pp. 41-44.

[14] Bojcevska, H., Tonderski, K., 2007. Impact of loads, season, and plant species on the performance of a tropical constructed wetland polishing effluent from sugar factory stabilization ponds. Ecol. Eng. 29 (1), pp.66– 76.

[15] Brix, H., Koottatep, T., Laugesen, C.H.,2007a. Wastewater treatment in tsunami affected areas of Thailand by constructed wetlands. Water Sci. Technol. 56 (3), pp.69–74.

[16] Bhuvaneshwari,M.,(2007),Alternanthera A.Sessilis and Marsileaquadrifolia as bioagents for wastewater treatment, M.Phil dissertation, Pondicherry University.

[17] Brix, H., and Schiereup, H.H. (1989). The use of aquatic macrophytes in water-pollution control, Ambio, 18:pp.100–107.

[18] Baker, 1998 L.A. Baker, Design considerations and applications for wetland treatment of highnitrate waters, Wat. Sci. Tech. 38 (1998), pp. 389–395

[19] Cooper, P.F. (2005). The performance of vertical flow constructed wetland systems with special reference to the significance of oxygen transfer and hydraulic loading rates, Wat. Sci. Tech. 51(9): pp.81-90.

[20] Bhupinder ,D. (2009) Salvinia: an Aquatic Fern with Potential Use in Phytoremediation , Environ. We Int. J. Sci. Tech.pp. 23-27.

[21] Cronk, J.K. and Fennessy, M.S. (2001) Wetland Plants - Biology and Ecology. Lewis Publishers, Boca Raton, Florida.

[22] Cakmak.B and H Apaydin 2010, Department of Farm Structures and Irrigation. Faculty of Agriculture. University of Ankara. Diskapi. Ankara 06110. Turkey

[23] Dombush, (1989) J.X. Dombush, Natural renovation of leachate-degraded groundwater in excavated ponds at a refuse landfill._ In. In:D.A. Hammer, Editor, Constructed Wetlands for Wastewater Treatment, Chelsea, Lewis (1989), pp. 743– 752.

[24] Dier berg, F. E., Débuts, T. A., Goulet, J. R. N. A. (1987). Removal of copper and lead using a thin-film technique. In K. R. Reddy &W. H. Smith (Eds.), Aquatic plants for water treatment and resource recovery (pp. 497–504). Magnolia.

[25] Duffer, W.R. (1982) Assessment of aquaculture for reclamation of wastewater in Joe Middlebrooks Water reuse. Ann. Arbor Sci., MI. pp. 349-367

[26] De Busk, W.F. (1999). Waste water treatment wetlands: Application and treatment efficiency. FAS extension, University of Florida.

[27] 27. EPA, 1993, EPA, (1993).Constructed wetlands for wastewater treatment and wild life habitat: 17 Case Studies. EPA 832 -R-93-005.

[28] Evans, G. M., Furlong, J.C (2003). Environmental Biotechnology Theory and Applications. John Wiley & Sons Limited. Pp.145-149

[29] Fisher, P. (1991). Wastewater Treatment Using Aquatic Plants. In: Appropriate Waste Management Technology Conference. Vol.1.Murdoch University, Perth.

[30] Ghunmi, L. A., G. Zeeman, et al. (2011) .Grey water treatment systems: A review Environmental Science and Technology 41(7): pp.657-698.

[31] Green, M.B., Griffin, P., Seabridge, J.K., Dhobie, D., 1997. Removal of bacteria in subsurface flow wetland. Water Sci. Technol. 35, pp.109–116.