

LOW COST TREATMENT OF SEWAGE USING ROOT ZONE TECHNOLOGY

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ABSTRACT

Large quantity of sewage is generated in urban and semi urban areas. Due to the lack of cost effective treatment methods, the world is facing problem of sewage treatment and disposal. Much advancement has taken place in the treatment technology both in aerobic and anaerobic methods. However, huge capital investment is required for providing treatment facilities, also disposal of the treated effluents is a major problem. The operation and maintenance cost in case of conventional sewage treatment plant is estimated to about Rs 12 per 1000 litres. As treatment cost is high, sewage is directly discharged into the rivers or nearby water bodies and polluting the major sources of water available to the society. The conventional methods are not feasible for small cities and towns. Hence there is a need of cost effective method for sewage treatment. Waste water treatment by Root Zone Technology (RZT) is emerging as the alternative low cost method which involves use of plants species for treatment of sewage. Studies were conducted to assess the feasibility of Root Zone Technology for sewage treatment. The study is conducted with pilot scale reactors on different types of plant species. The reactor of size 1.3m x 0.65m x 0.40 m made in PVC material was used for the study. Plants species were planted in the reactor and were irrigated initially with tap water. After stabilizing the reactor, different doses of sewage was applied at regular interval of 3 days and growth of plants was observed. After steady state is reached, hydraulic loading was determined to get zero discharge. The quality of treated waste water was assessed when the reactor was loaded with excess hydraulic loading. The reactor was found be very effective for sewage treatment. COD reduction of 88.18%, BOD reduction of 88% and solids reduction of 69.23% was observed during the study. The cost economics of Root Zone Technology was assessed to Rs 4.13 per 1000 Litters. This reveals the economical and efficient method for sewage treatment and disposal which will be useful to the small towns and isolated institute.

Key Words : Sewage, Root Zone Technology, COD, BOD, Cost effective treatment methods, Zero discharge

INTRODUCTION

Environment pollution is one of the serious problems that the world is facing in this era. In India, major problem leading to environment pollution is increasing population, industrialization and urbanization. Collection, treatment and disposal of domestic and industrial wastewater are the serious issues to be handled for preventing damage to the environment. A 2007 study finds that discharge of untreated sewage is single most important cause for pollution of surface and ground water in India. There is a large gap between generation and treatment of domestic wastewater in India. There

is lack sufficient treatment capacity and also the existing sewage treatment plants are not operated properly and maintained in good running condition. The wastewater generated in these areas normally percolates in the soil or evaporates. The uncollected wastes accumulate in the urban areas cause unhygienic conditions and release pollutants that leach to surface and groundwater.

Wastewater generated in these areas normally traditional waste water treatment plant includes processes like primary sedimentation, aeration, secondary treatment and chlorination. This form of treatment plants requires high initial investment. Moreover their maintenance cost is

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high and treatment plant requires large land area. For the functioning and proper maintenance of the plant skilled labours are required. Overall the treatment plants are costly affair and results are not up to the mark. Treatment of waste water by traditional method is very costly and hence neglected by most of the public bodies. The main objective of this study is to develop cost effective treatment technology for sewage treatment. Assessment of root zone technology for sewage treatment and disposal is conducted.

The term 'Root Zone' encompasses the life interactions of various species of bacteria, the roots of reed plants, soil, sun and water. They are also known as constructed wetlands or sub-surface flow systems. In this system, these plants conduct oxygen through their stems into their root systems and create favourable conditions for the growth of bacteria. The wastewater flow through the root zone in a horizontal or vertical way, where the organic pollutants are decomposed biochemically by the bacteria present in the rhizosphere of root plants. The filter media are selected carefully to provide favourable conditions for both plants and bacterial growth and to avoid clogging. Organic pollutants are removed drastically from wastewater and are reduced to their elemental forms. It also has to potential to accumulate heavy metals in the root zone.

The root zone treatment systems have wide range of applications in treatment of different types of waste waters such as domestic and industrial waste water containing biodegradable matter including some, which are difficult to treat by other means. There are various benefits of using root zone technology such as follows low capital costs, low operating and maintenance costs, no need of technical expertise, environmentally safe and friendly method. No by-products are produced in this method and it is long lasting.

Literature review

S.Dipu et al.¹ conducted studied and compared the efficiency of aquatic macrophytes like *Typha* sp., *Eichhornia* sp., *Salvinia* sp. and *Pistia* sp. to treat the effluents from dairy factory in constructed wetlands. The biological oxygen demand, chemical oxygen demand turbidity, nutrients and total solids of dairy effluent was reduced significantly ($p < 0.01$) after treatment. The *Typha* based treatment system was the most

efficient in removing the pollutants from the effluent. So in conclusion, emergent species were more efficient than the floating macrophytes in constructed wetland technology.¹ Horizontal sub-surface flow constructed wetlands (HF CWs) Ondřejov and Spa'lene' Por'ic'í' the oldest systems in the Czech Republic were operated since 1992 by Jan Vymazal.² CW Ondřejov treats sewage from 362 PE in a single 806 m² bed planted with *Phragmites australis*. Six beds were planted with a mixture of *P. australis* and *Phalaris arundinacea* with a total area of 5000m². Constructed wetland Ondřejov treatment performance was found steady over the period of operation and exhibited "typical" efficiency for organics (average BOD5 inflow and outflow concentrations of 198 mg l⁻¹ and 18 mg l⁻¹, respectively) and suspended solids (average inflow and outflow concentrations 204 mg l⁻¹ and 9mg l⁻¹, respectively).

Using constructed wetlands, wastewater can be treated at lower costs than other treatment options, with low-technology methods where no new or complex technological tools are needed.³ The system relies on renewable energy sources such as solar and kinetic energy and wetland plants and microorganisms, which are the active agents in the treatment process. There are inherent limitations to the effectiveness of rhizosphere treatment system for wastewater treatment. Preetha R., et al.³ concluded that rhizosphere treatment is often the best choice for treatment or pre-treatment of wastewater because of low maintenance cost and simplicity of operation and high efficiency and to add, they enhance the aesthetic value of the local and conserve the fauna and flora.

The rapid urbanization has resulted in putting excess pressure on infrastructure facilities resulting in low level of services provided by local authorities. The sewage flowing through nallahs joins rivers in untreated condition and creates heavy risk of river pollution.^{4,5} investigated the effectiveness and techno economical feasibility for RZTS (Root zone treatment system) along with it's modification. Their suggested modification in RZTS reduces the limitations of huge area requirement for application of conventional RZTS (Constructed wetland) and the modified constructed wetland

(modified RZTS) can be effectively used within the nallah area to treat incoming waste water in nallah with techno economical feasible option. The studies based on experimental results and its analysis modified constructed wetland (Modified Root Zone Treatment System), it is seen that the average BOD removal efficiency of designed unit (modified design of RZTS and trickling bed) is 85.25% upto 0.5m root zone bed depth, and is of average 79.45% for total 1.5m combined bed depth. The average COD removal efficiency of designed unit (modified design of RZTS and trickling bed) is 85.25% upto 0.5m root zone bed depth, and is of average 79.45% for total 1.5m combined bed depth. The average TSS removal efficiency of designed unit (modified design of RZTS and trickling bed) is 91.83% up to 0.5m root zone bed depth, and is of average 83.07% for total 1.5m combined bed depth.^{4,6-8}

Csilla T., et al⁹ reported that the constructed wetland is a near-natural wastewater treatment technique, where reed (*Phragmites australis*) is an important component. The high rate of small residential settlements (less than 2000 Population Equivalent (PE) in Hungary suggests the consideration of cost-effective, locally operating wastewater treating methods. The pollution removal capacity with the near-natural root-zone technology was compared with conventional activated sludge plant. They reported that reed bed system has stable removal efficacy of organics of a similar rate to the conventional technologies, while in view of nutrients they have higher retention ability, and therefore beneficial against eutrophication.⁹

Field tests were conducted and historical operating data were evaluated to assess the performance of the Monterey WWTP utilizing Subsurface Flow (SF) constructed wetlands.¹⁰ Collection and analysis of historical operating data from January 1998 to May 2000 revealed a constantly decreasing removal of Carbonaceous Biochemical Oxygen Demand (CBOD5) by the SF wetlands and a poor removal of ammonia-N throughout the system. Analysis of field data also showed that the SF wetlands removed 88% of the influent TSS

and 71% of the influent CBOD5, while experiencing a 18% increase in ammonia-N. Bisulfide produced in the anaerobic wetland beds accounted for 95% of the chlorine lost in contact tank. Vipat V., et al¹⁰ conducted studies for finding efficiency of treatment of field scale root zone treatment systems for treatment of domestic sewage in Bhopal city. Satisfactory performance was reported for the field scale treatment system as indicated by 100% removal of organic nitrogen, 98.7% removal in Coli form bacteria, 77.81% removal of COD and 79% removal of total suspended solids.¹¹

The root zone treatment systems are classified as horizontal flow and vertical flow system. Details of the two systems are shown in **Fig. 1** and **Fig. 2**.

Various plants available for root zone treatment systems are *Phragmites australis* (reed), *Phragmites karka* (reed), *Arundo donax* (mediterranean reed), *Typha latifolia* (cattail), *Typha angustifolia* (cattail), *Juncus* (bulrush), *Iris pseudacorus*, *Schoenoplectus lacustris* (bulrush).

Planting technique⁷

Reeds can be planted as rhizomes, seedlings or planted clumps. Clumps can be planted during all seasons at 2 no. / m². Rhizomes grow best when planted in Pre-monsoon and 4 – 6 rhizomes can be planted per m². Seedlings should be planted in Pre-monsoon with 3 – 5 seedlings per m². Planting should be done from supporting boards to avoid compaction of the filter media. Initially the plants should be kept well watered, but not flooded. With well-developed shoots, the growth of weeds can be suppressed by periodical flooding. During the first growth period a sufficient supply of nutrients is required. If wastewater is used for initial watering precautions like avoidance of stagnation have to be taken to inhibit the formation of H₂S within the filter bed.^{12,13}

Working of Root Zone Technology

The functional mechanisms in the soil matrix that are responsible for the mineralization of biodegradable matter are characterized by complex physical, Chemical and biological processes, which result from the combined effects of the filter bed material, wetland plants, micro-organisms and wastewater.

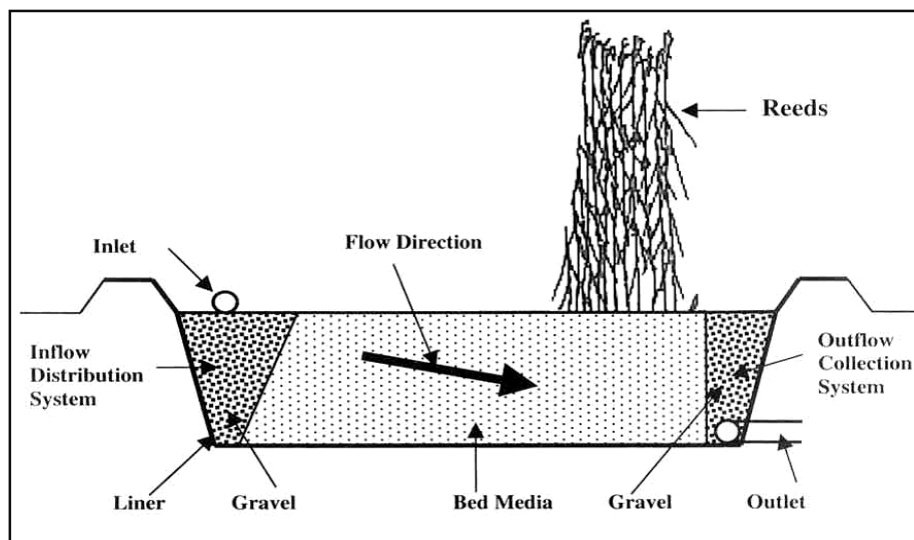


Fig. 1 : Horizontal (flow system) root zone filter

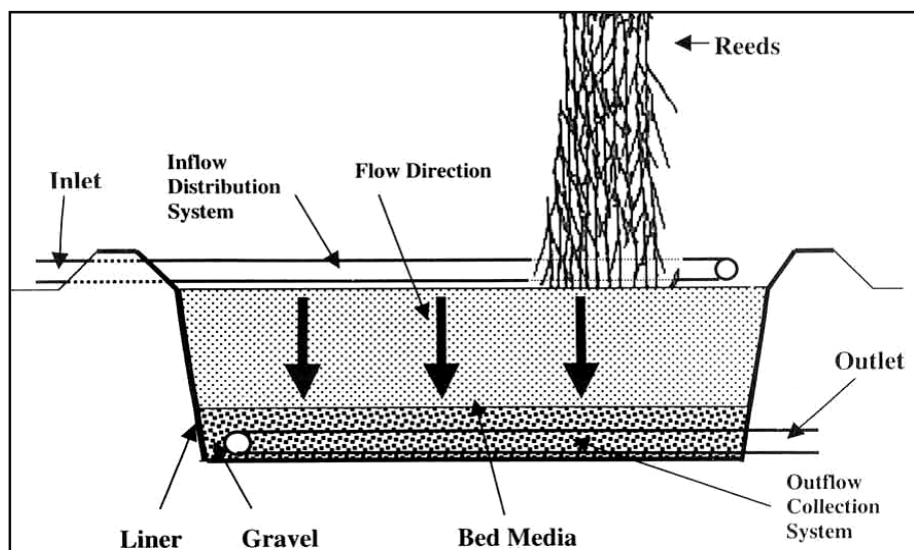


Fig. 2 : Vertical (flow system) root zone filter

The treatment processes are based essentially on the activity of microorganisms present in the soil. Smaller the grain size of the filter material and consequently larger the internal surface of the filter bed higher would be the content of microorganisms. Therefore, the efficiency should be higher with finer bed material. This process, however is limited by the hydraulic properties of the filter bed; finer the bed material, lower the hydraulic load and higher the clogging tendency. The optimization of the filter material in terms of hydraulic Load and biodegradation intensity is therefore the most important factor in designing RZTS.

The oxygen for microbial mineralisation of organic substances is supplied through the roots of the plants, atmospheric diffusion and in case of intermittent wastewater feeding through suction into the soil by the out flowing Wastewater. The roots of the plants intensify the process of biodegradation also by creating an environment in the rhizosphere, which enhances the efficiency of microorganisms and reduces the tendency of clogging of the pores of the bed material caused by an increase of biomass.

RZTS contain aerobic, anoxic and anaerobic zones. This, together with the effects of the rhizosphere causes the presence of a large

number of different strains of microorganisms and consequently a large variety of biochemical pathways are formed. This explains the high efficacy of biodegradation of substances those are difficult to treat.

The filtration by percolation through the bed material is the reason for the very efficient reduction of pathogens, depending on the size of grain of the bed material and thickness of filter, thus making the treated effluent suitable for reuse.

Conversion of nitrogen compounds (Nitrification / Denitrification) occurs due to planned flow of wastewater through anaerobic and aerobic zones. Reduction of phosphorous depends on the availability of acceptors like iron compounds and the redox potential in the soil.

MATERIAL AND METHODS

Construction of reactor

Studies were conducted to assess the feasibility of Root Zone Technology (RTZ) for sewage treatment. The study is conducted on pilot scale reactors on different types of plant species. Pilot scale reactors of size 1.3m x 0.65m x 0.40 m was used for the present study. Plants were irrigated with sewage at regular interval of 5 days and growth of plants is observed. The sewage required for the study was collected from sewage

treatment plant of Nashik city. The sewage sample was given pre-treatment of trickling filter for removal of suspended solids and partial BOD removal. Different plants are irrigated with sewage with dosage starting from 25% of sewage to 100 % of sewage. Studies were conducted initially with four plant species. The plant showing proper growth under 100% dosing was selected for further study. After steady state is reached, the quality of treated sewage effluent was assessed. The hydraulic loading rate and quality of treated effluent, hydraulic loading for zero discharge treatment, cost economics were the parameters under consideration.

Inlet arrangement

Inlet arrangement consisting a pilot scale trickling filter of diameter 0.3 m and height of 0.4m was used. Filter media consisting of crushed aggregate of size gradation 10mm at top to 40mm at bottom was provided. The filter media was provided in three layers each of 0.15 m in height. A plastic pipe is provided to collect the filtered sewage at bottom as shown in **Fig. 3**.

Construction of reactor

Various steps involved in construction of the reactor are shown in **Fig. 4** and **Fig. 5**. These figures show the details during development of the pilot scale RZT reactor.

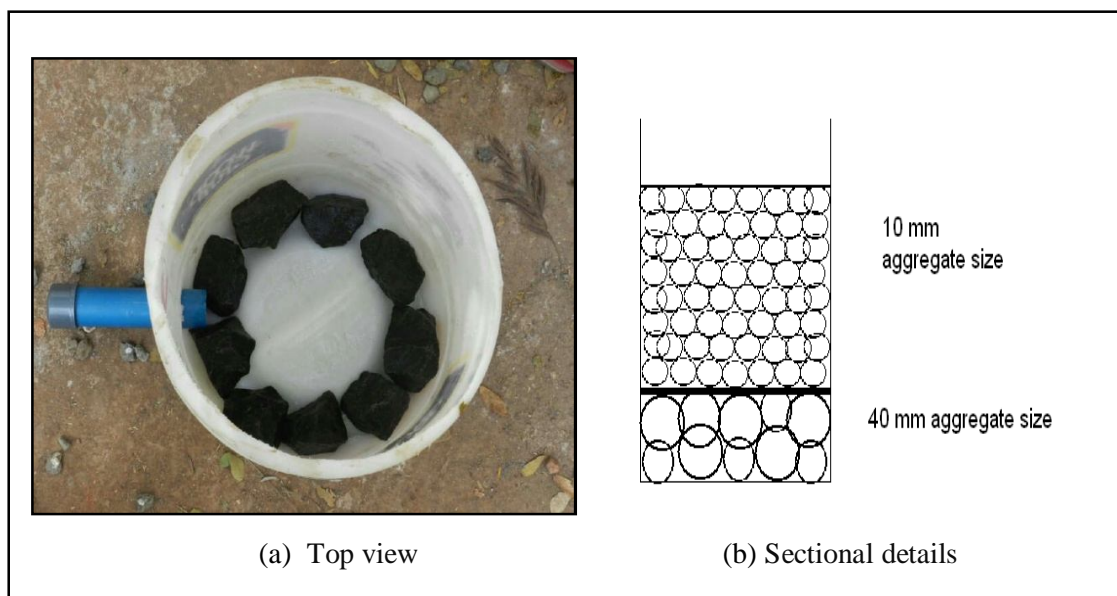


Fig. 3 : Trickling filter

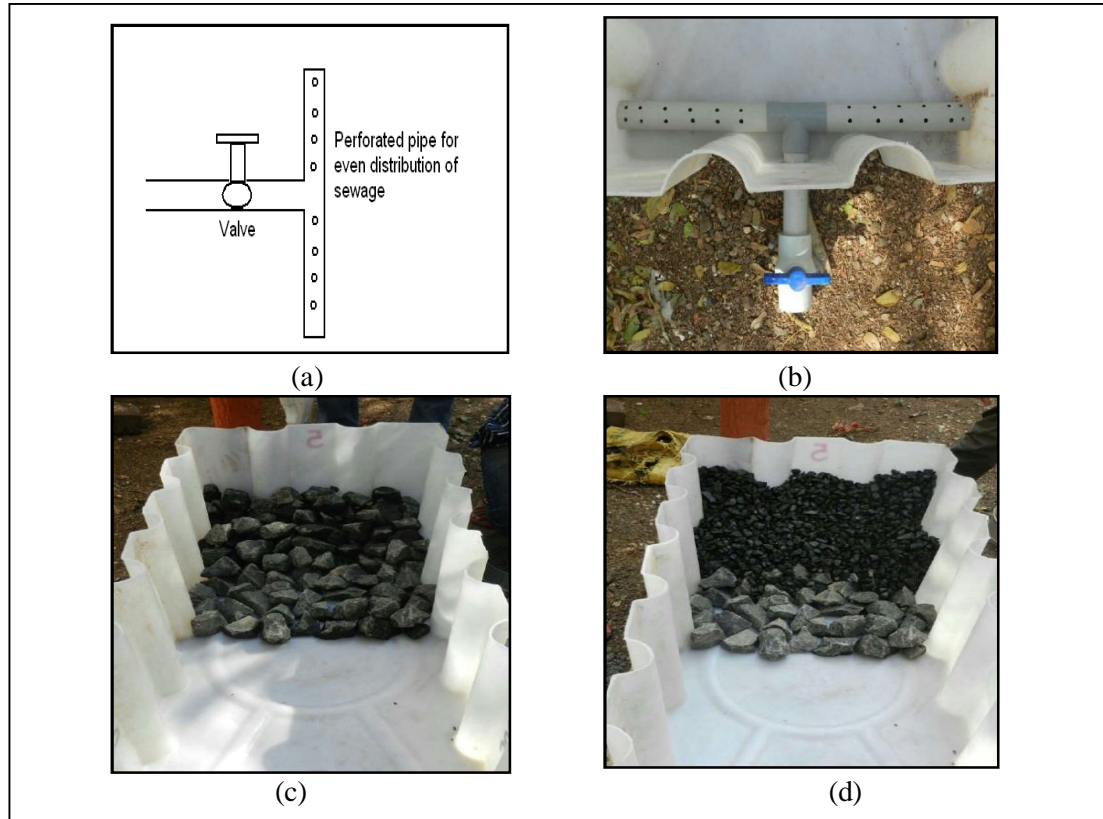


Fig. 4 : Development of Root Zone Treatment (RTZ) system reactor: a) distribution pipe at top (inlet) b) underdrainage pipe at bottom (outlet) c) constructional details d) constructional details

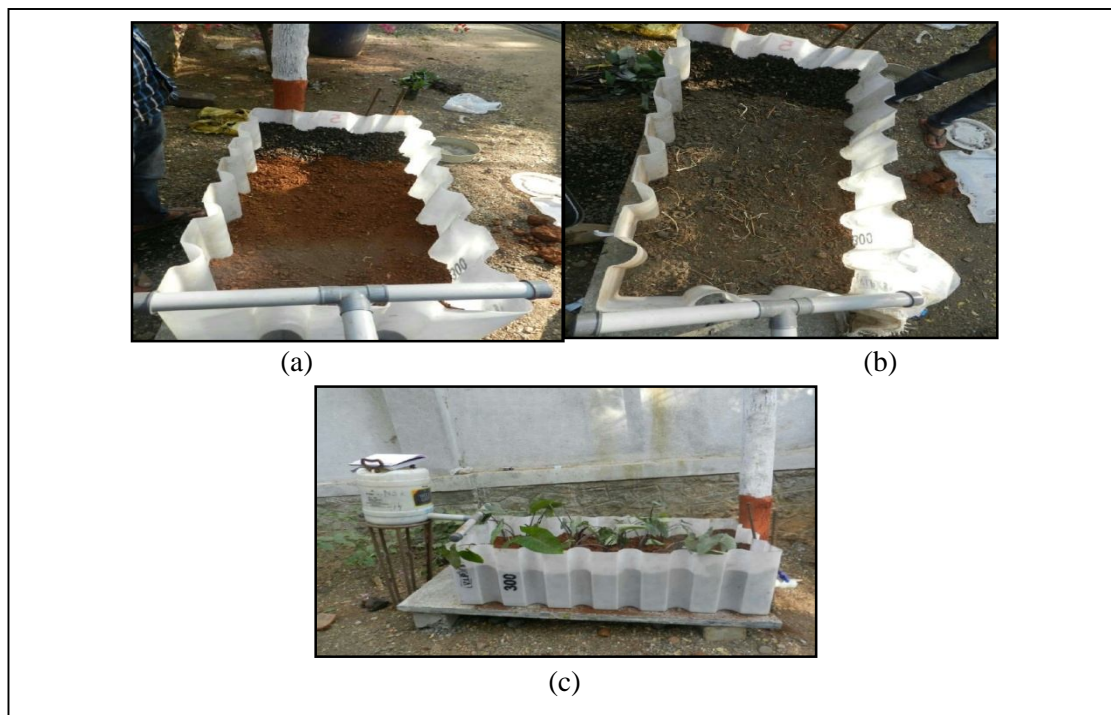


Fig. 5 : Construction of pilot scale RZT reactor a) soil layer b) compost layer c) final set up after plantation

To prevent entry of soil into under drain pipe and washing out of soil a graded filter is provided at the blower portion of the reactor. The filter consist of crushed stone of gradation 40mm at bottom near to under drain pipe to 5mm at top just below the soil layer. A fertile soil layer of 20 cm thickness is provided above the filter. Over this 1-2cm thick layer of organic compost is laid over the soil layer. Plantation is done after these layers are laid and plants are watered. Different species of plants were considered for plantation in RZT system. Considering local availability, ability to consume the organic and inorganic matter from waste, and revenue by selling the plant, Elephants Ear or Arum was considered as the plant species in the RZTS.

Working of the reactor

Watering

The complete reactor set up after plantation is as shown in **Fig. 5**. The reactor was watered through the trickling filter. Water was stored in the filter by closing the drain valve and the media was kept moist. Storage capacity of trickling filter was found to be 8 liters. After plantation, watering of the reactor was carried out with tap water. Watering with tap water was continued till proper growth of the plants. After 20 days growth of the plants was noticed

indicating steady state of the reactor. The volume of water applied was just sufficient to keep soil in wet condition and till to get water at the outlet. The quantity of water required to keep saturated condition was found to be 50 Litres. Watering of 50 litres was continuously applied at interval of 3days.

Sewage feeding

After reactor was stabilized in about 20 days with tap water, doses of sewage applied with percentage of sewage increase at 10%. Each dose was continued for two watering that is 6 days then next higher dose was applied. Gradual increase in sewage dose was done so that the plants adapt the quality of water. Thus 100% sewage application to the reactor was done after 53 days from initial loading of 10% sewage dosing. The loading of 100% sewage was carried out continuously and the growth of plants was observed. Samples were collected at the inlet and outlet and analysed for determining quality in our laboratory for various parameters like solids, BOD, COD as per APHA Standard methods. The detailed schedule of watering and sewage loading is given in **Table 1**. Time is measured from the day of plantation of the species in the pilot scale Root Zone Treatment (RZT) reactor.

Table 1: Details of watering to the reactor

Time in days after plantation	Percentage of sewage in the feed water	Total quantity of water (L) applied at every 3 rd day
0-20	0	50
21	10	50
27	20	50
33	30	30
39	40	50
45	50	50
51	60	50
57	70	50
63	80	50
69	90	50
75	100	50

Performance of evaluation

Hydraulic loading rate

The total quantity of required to saturate the reactor is 50 liters Zero discharge of treated effluent is obtained when dosing interval is more than 3 days. However, when the watering

interval applied is less than 3days then discharge is obtained at the outlet. The treated discharge was measured and found to be 30 litres for watering of 50 litres in interval less than 3 days. Mass flow equation for the sewage flow applied to the reactor is as shown below.

$$Q_{in} = Q_{ut} + Q_{out}$$

Where ,

- Q_{in} = Quantity of sewage applied to the reactor in l/day.
- Q_{ut} = Quantity of the sewage consumed by the reactor in l/day.
- Q_{out} = Quantity of the treated effluent in l/day.

Thus, it is estimated that 20 Litres was utilised in the reactor by the plants for their growth. The Hydraulic Loading Rate (HLR) is calculated as below.:

$$\text{Area of the reactor} = 0.7424 \text{ m}^2.$$

Quantity of the sewage applied to the reactor to produce saturation condition = 50 litres.

Therefore, Hydraulic Loading Rate (HLR) =

$$\text{HLR} =$$

$$= \frac{\text{Quantity of sewage in liters applied to the reactor.}}{\text{Surface area of the reactor.}}$$

$$= \frac{50}{0.7424}$$

$$= 67.35 \text{ L/m}^2.$$

Hence the Hydraulic Loading Rate of the reactor is found to be 67.35 l/m² or 0.06735 m³/m²/day. Now if the Hydraulic Loading applied is less than 67.35 l/m²/day then the reactor will utilise all the sewage and this

condition is defined as the zero discharge condition. Also when HLR is 67.35L/m² and watering interval is more than 3 days produces zero discharge. However when watering interval is less than 3days then treated discharge of 30 Litres is obtained. Also for Hydraulic loading rate applied exceeds 67.35 L/m² and watering interval of 3 days or less produces treated discharge of about 30 L. Samples were collected at the inlet and outlet of the reactor and analysed for various parameters like solids, BOD, COD as per APHA Standard methods determining quality in our laboratory. The results of analysis are given in **Table 2**.

Mass balance for Chemical Oxygen Demand (COD) for the reactor can be written as below.

$$t(COD)_{in} = t(COD)_{tr} + t(COD)_{ef}$$

Where,

- $t(COD)_{in}$ = Total COD applied to the reactor in kg/day= Q x COD_{IN}.
- $t(COD)_{tr}$ = Total COD treated by the reactor in kg/day= Q x (COD_{IN} - COD_{EF}).
- $(COD)_{ef}$ = Total COD leaving the system in kg/day= Q x COD_{EF}.

Where, COD_{IN} and COD_{EF} are the COD of the raw and treated sewage respectively

Table 2 : Results of various tests parameters

S/N	Test parameters	For raw sewage	For treated effluent
1	Total solids	520 mg/l	160 mg/l
2	Total dissolved solids	120 mg/l	20 mg/l
3	Total suspended solids	400 mg/l	140 mg/l
4	COD	220 mg/l	26 mg/l
5	BOD	125 mg/l	15 mg/l
6	DO	0 mg/l	0 mg/l

RESULTS AND DISCUSSION

Cost analysis of Root Zone Technology

Cost is an important consideration because future of any project depends on the initial investment, operational and maintenance cost. Cost analysis is done for both conventional

methods of treatment of sewage as well as Sewage treatment using Root Zone Technology and feasibility of it is determined for sewage treatment for small towns and isolated institute. Sewage treatment plant of 1 MLD is considered for comparative study for both cases.

Cost analysis for conventional method of sewage treatment

Cost analysis for conventional treatment with Activated Sludge Process (ASP) including primary treatment, secondary treatment and chlorination is given below

Construction cost of ASP plant = 70 lakh per MLD.

Land requirement / MLD plant = 1 acre.

Land cost/MLD = 20 lakh per acre.

Therefore Capital Investment required for setting up 1MLD sewage treatment plant consisting activated Sludge process = Cost of construction + Cost of land required = 70,00,000 + 20,00,000 = Rs 90,00,000 /-

The operational and maintenance cost including interest on capital, electricity consumption, skilled and unskilled labour cost, repair and maintenance cost and depreciation of civil and mechanical works ,revenue obtained is worked out to Rs 12 per 1000 litres of sewage.

Thus the operation and maintenance cost for operating conventional sewage treatment plant of 1 MLD is about Rs 4380000/year

Cost analysis of Root Zone Technology treatment plant

For comparing the cost economics of root zone technology with conventional method, sewage treatment plant of 1MLDconsisting root zone technology is considered.

Land requirement/MLD = 3.5 acre.

Cost of land = 30 lakh per acre X 3.5 acres=70 lakh.

Cost of excavation for construction of RZT reactor = 18 lakh.

Cost of filter media = 40 lakh.

Cost of polythene sheeting = 14 lakh.

Therefore capital investment required for setting up the Root Zone Technology (RTZ) treatment plant,

= Cost of construction + Cost of land

= (18 lakhs + 40 lakhs + 14 lakhs) +105 lakhs = Rs 177 lakhs /-

The operational and maintenance cost or treatment cost is determined considering following items,

- i) Labour for watering, cutting and maintenance.

= 3 labour per acre x Rs 200 x 365 days x 3.5 acre.

= Rs 7, 67,000 /-

- ii) Interest on investment at 8 % = Rs 1416000 /-

- iii) Revenue generated from plants per year = Rs 6,00,000 /-

Treatment cost=Labour cost+ Interest on investment at 8% - Revenue obtained by selling the plant.

Treatment Cost = 7,67,000 + 1416000 - 6,00,000= Rs 15,08,000 /-

Total sewage treated per year = 365X 1 MLD=365 million litres=365 X 1000 X1000 litres. Therefore treatment cost per m³ of sewage =(1508000)/(365X1000)= Rs 4.13/- Therefore the treatment cost of sewage using Root Zone Technology is Rs 4.13 per 1000 litres or Rs 4.13 per m³ which is very less as compared to the treatment cost of Rs 12 per m³ for Conventional Sewage treatment .

CONCLUSION

Treatment of sewage and disposal of treated sewage is a major problem in Indian cities. Construction of treatment facilities require huge capital investment, operation of the conventional treatment plant is very costly. Because of these factors sewage treatment is most neglected aspect in our country. It is resulting into pollution of rivers and also ground water resources. There is a large gap between generation and treatment of domestic wastewater. Therefore cost effective sewage treatment is the requirement of the time for protecting the environment.

Studies were conducted to find suitability of root zone technology for sewage treatment. The results of the study with pilot plant reactor shows that root zone technology is economical solution for sewage treatment generated in small towns and isolated institutes.

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