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# REED BEDS FOR THE TREATMENT OF TANNERY EFFLUENT

*Prepared by*

**K.V. Emmanuel**
**National Expert-Environmental Engineering**

*Project Manager*

**Jakov Buljan**
**Agro-industries and Sectoral Support Branch**

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## Project Team

1. Jakov Buljan, Project Manager
2. A. Sahasranaman, Programme Coordinator
3. Richard Daniels, UNIDO Consultant
4. S. Rajamani, Technical Expert (until January 1999)
5. K.V.Emmanuel, National Expert
6. G. Anand, The Solutions Centre
7. D. Rajamoorthy, ETP Manager, Presidency Kid Leathers Ltd
8. I. Sajid Hussain, Plant Manager, CETP-Ranitec
9. J. Irshad, Plant Chemist, CETP-Vishtec
10. P.R. Kavitha, Technical Manager, CETP-SIDCO.

## LIST OF SYMBOLS & ABBREVIATIONS

| | | |
|---|---|---|
| $BOD_5$ | : | Biochemical Oxygen Demand, 5 days at 20°C |
| COD | : | Chemical Oxygen Demand |
| CETP | : | Common Effluent Treatment Plant |
| $Cr^{3+}$ | : | Trivalent chromium |
| °C | : | Degree Celsius |
| D.S. | : | Dry Solids |
| d | : | Day(s) |
| dia | : | Diameter |
| d.w. | : | Dry weight |
| ETP | : | Effluent Treatment Plant |
| ft | : | Foot |
| h | : | Hour(s) |
| H | : | Height |
| HCl | : | Hydrochloric acid |
| HDPE | : | High density polyethylene |
| HP | : | Horse power |
| INR | : | Indian Rupees |
| kg | : | Kilogram |
| kWh | : | Kilowatt hour |
| LDPE | : | Low density polyethylene |
| l/sec | : | Litre(s) per second |
| m | : | Meter(s) |
| $m^3$ | : | Cubic meter (1000 litres) |
| mg/l | : | Milligrams per litre |
| min | : | Minute(s) |
| N | : | Nitrogen |
| no. | : | Number |
| P | : | Phosphates |
| PVC | : | Polyvinyl chloride |
| PCC | : | Plain Cement Concrete |
| PDU | : | Pilot Demonstration Unit |
| pH | : | Negative logarithm of hydrogen ion concentration |
| RCC | : | Reinforced Cement Concrete |
| RePO | : | Regional Programme Office of UNIDO at Chennai |
| s | : | Second(s) |
| SS | : | Suspended Solids |
| t | : | Tonne (1000 kg) |
| UNIDO | : | United Nations Industrial Development Organisation |
| US $ | : | United States Dollar(s)* |
| W | : | watt(s) |

(Rate of exchange: 1 US $ = INR 46.80)

# EXECUTIVE SUMMARY

Conventional technologies for treatment of tannery effluent are generally energy & chemical intensive. Besides continuous process control is required to achieve optimum results. In the search for alternative robust, easy to operate and low maintenance treatment technologies, constructed wetland system, also known as root zone treatment system, using reeds for treatment of effluent, has been considered a possibility. This system is widely used in Europe and elsewhere to treat municipal sewerage. However, in absence of application of this system for treatment of tannery effluent anywhere in the world at present, doubts remained with regard to its efficiency and technical viability. Accordingly, in cooperation with willing tanneries and effluent treatment plants in Tamilnadu, India, UNIDO, under its Regional Programme, established four pilot and demonstration reed beds, each with different features, to deal with effluent of different characteristics.

The main objectives of these pilot reed beds are:

- Identification of reeds resistant to salinity and suitable for treating tannery effluent;
- Evaluation of various features of reed beds such as (a) flow pattern – horizontal or vertical, (b) media – soil versus gravel, (c) mode of treatment – continuous versus fill and draw system and (d) serial versus parallel operation in case of multiple beds;
- Evaluation of efficacy of reed beds as (a) tertiary / polishing treatment of treated effluent, to achieve consistency of colour, BOD and COD and (b) partial or total replacement of biological treatment; and,
- Developing the design for a model ETP, with reed bed as a part of it, for treatment of tannery effluent.

A full-scale reed bed treatment plant of 50 $m^3$/d capacity, set up in cooperation with Presidency Kid Leather P. Ltd. (PKL) near Chennai in Tamilnadu, India, was initially tried as a tertiary treatment system and later as a partial replacement of conventional biological treatment system. This reed bed has been operational since August 1998. Regular and meticulous monitoring of the performance has yielded valuable data. The efficiency of reed bed for tertiary treatment of effluent has been compared with other known tertiary treatment systems such as ozonation, activated carbon and chemical oxidation and results tabulated.

As at the PKL tannery the effluent treated has TDS level of generally less than 5000 mg/l., another pilot, but more basic, reed bed, 50 $m^3$/d capacity, was set up at CETP-Vishtec, Melvisharam which treated effluent with TDS of > 10000 mg/l. It has been operational since July 1999. Not only have specific local reeds survived in high saline effluent but the treatment efficiency of the reed bed compared very well with that of conventional biological treatment system while treating primary treated effluent.

Two small reed beds, each of 5 $m^3$/d capacity, were set up by the CETP managements at CETP-SIDCO and CETP-Ranitec both in Ranipet, Tamil Nadu, India using different media and design features with UNIDO's technical assistance in 1998. UNIDO has been very closely involved in the monitoring of these reed beds too.

Focus of all efforts has been to arrive at reliable design features, behaviour pattern of different varieties of reeds and their efficacy, performance of different media and the overall relevance of the system for treatment of tannery effluent.

Based on the large volume of data generated from the reed beds set up and operational for more than 2 years now, the following conclusions have been made:

- It has been found that sieved coarse sand (preferably of size 2 to 5 mm) serves as an effective media in reed beds.

- Salinity in the tannery effluent has not been found to affect the survival of reeds or operation of reed beds. Many reeds of local varieties such as Typha angustifolia, Scirpus robustus and Trema Orientalis survived and thrived well in tannery effluent. Of late phratmite australis, considered a very efficient reed, too has been found to survive and propagate well in the pilot reed beds.

- Continuous horizontal feeding system has been found to give good results.

- For tertiary treatment, the optimum retention period was found to be 3 days; and for biological treatment, 3.5 days.

- As tertiary treatment, the reed beds obtained 50-60% organic removal efficiency (better than any other common tertiary treatment system) with better colour and turbidity removal.

- As a replacement of biological treatment system, the mean reduction of BOD was 87.31% and of COD, 74.9%, during the monitoring period.

- Frequency of harvesting of reeds will depend on the strain of reeds used; often it has been found necessary to harvest reeds of local strains at least once in eight months. However, harvesting reeds has not been found to adversely impact on its efficiency.

Among the advantages of the reed beds are: robust treatment system with very low maintenance and negligible use of energy. Chemicals are not required for the reed bed itself but physico-chemical treatment is the first stage of treatment in the ETP before effluent can be charged to it.

The limitations include rather large requirement of land (3 to 5 times more than that for conventional treatment), availability of good strains of local reeds or finding sturdy strains, somewhat long gestation period and vulnerability of some reeds to fluctuating characteristics and/or shock loads of the influent.

The reed bed established at PKL, due to its robust construction and extra provisions for close monitoring, cost about US \$ 1000/$m^{3}$. as against the average installation cost of US \$ 700 – 800 / $m^3$ for conventional biological treatment system. The more basic reed bed at CETP-Vishtec cost US \$ 300 / $m^3$. The operational cost of the reed bed was US \$ 0.13 - 0.25 /$m^3$ as against that of US \$ 0.4 - 0.5 / $m^3$ for conventional biological treatment system.

Based on experience gained from the pilot units, the conceptual design for an effluent treatment plant inclusive of a reed bed for biological treatment, with provision for better hydraulic conductivity and protection against likely adverse impact due of fluctuations in the inlet suspended solids load, has been included in the report.

## 1. BACKGROUND

In conventional tannery effluent treatment plants chemicals and energy are used to treat effluent for achieving prescribed discharge standards. In many developing countries due to poor make and maintenance of machinery and equipment frequent breakdowns result. Also despite satisfactory operation of the effluent treatment plants the discharge standards are not consistently reached. One of the options considered in the context of developing countries is to evaluate the relevance and specific application potential of natural treatment systems, especially constructed wet land system, popularly known as reed beds. Though reeds beds have been successfully operated in Europe and elsewhere for treating domestic and some types of industrial effluent no specific experience of treating tannery effluent by reed beds existed. Accordingly, under UNIDO's Regional Programme, it was decided to evaluate the feasibility of application of reed beds for treatment of tannery effluent.

## 2. OBJECTIVES

- Identification of reeds resistant to salinity and suitable for treating tannery effluent.
- Demonstration and evaluation of various features of reed bed based on (a) Flow pattern: horizontal vs. vertical (b) Media: soil vs. gravel and (c) Mode of treatment: continuous vs. fill and draw system.
- To evaluate the efficacy of reed bed as (a) a tertiary / polishing treatment of treated effluent with a view to achieve consistency of results for BOD/COD and possibly, colour; and, (b) partial or total replacement of biological treatment.
- Evaluation of operational patterns, e.g. serial vs. parallel operation in case of multiple beds.
- Preparation of a model ETP design inclusive of reed bed for tannery effluent as a low maintenance treatment system.

## 3. STRATEGY & AGENCIES INVOLVED

The strategy adopted was:

- To set up a reed bed in an ETP (Presidency Kid Leather (P). Ltd., Kannivakkam, Tamil Nadu, India) treating effluent from a tannery processing semi-processed hides / skins to finished leather, the effluent from which contains TDS generally below 5000 mg/l. It was envisaged initially to evaluate its efficacy as a tertiary treatment system and later as a biological treatment system.

- To set up a nursery in the CETP-Vishtec, Melvisharam, treating effluent with high TDS (above 10000 mg/l), to evaluate the survival of specific varieties of reeds in such effluent and subject to healthy survival of the reeds in such effluent, to set up a more basic reed bed system there.

- To set up experimental plots to study effectiveness of reed bed as tertiary treatment system in two other locations, one with low TDS and one with high TDS. CETP-SIDCO & CETP-Ranitec, both in Ranipet, were identified for the purpose.

Following agencies were involved in the implementation of the project.

- The Solutions Centre, Cochin, India (subcontractor for the design, supervision and monitoring of the reed beds).
- Mr. Richard Daniels of the United Kingdom as an international consultant.
- PKL (P) Ltd., Kannivakkam, India.
- CETP-Vishtec, Melvisharam, India.
- CETP-SIDCO, Ranipet, India.
- CETP-Ranitec, Ranipet, India.

# 4. WET LAND SYSTEMS

## 4.1 Types of Wetland Systems

A wide variety of wetland systems can be employed for treatment of industrial effluent. The various options include:

- Free floating macrophyte - based systems
- Rooted emergent macrophyte - based system
- Submerged macrophyte - based system
- Multi-stage systems consisting of a combination of the above mentioned concepts and other kinds of low - maintenance systems (e.g. Oxidation ponds)

### *4.1.1 Free-floating macrophyte based system*

Free floating macrophyte based systems 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. water hyacinth) to minute surface floating plants with few or no roots (e.g. duck weeds). Water hyacinth is one of the most prolific and productive plants in the world. The high productivity is exploited for wastewater treatment. Two different concepts are applied in water hyacinth based treatment systems.

i. Nutrient removal in which nitrogen and phosphorous are removed from effluent by their assimilation in the hyacinth biomass.
ii. BOD and nutrient removal, where degradation of organic matter and microbial transformation of nitrogen (nitrification - de nitrification) proceed simultaneously in the hyacinth based system.

Water hyacinth based systems are also known for their efficiency in removal of suspended solids and heavy metals. The retention time in a hyacinth based system, though dependent on the characteristics of the effluent and the treatment requirements, usually is in the range 5 - 15 days.

Duckweed - based systems, though having wider geographic range due to their ability to sustain in very low temperatures (as low as 1$^{o}$C), have much lower efficiency than water hyacinth based system due to the absence of extensive root system. The extensive root system of water hyacinth facilitates

i) provision of a huge surface area for attached micro-organisms thereby increasing the potential for decomposition of organic matter
ii) high rate of transfer of oxygen from the foliage to the rhizosphere providing sufficient oxygen for degradation of organic matter.

However, the water hyacinth systems are highly sensitive to salinity of the influent. It has been observed that seawater intruding into the backwaters causes mass destruction of water hyacinths.

### *4.1.2 Emergent aquatic macrophyte - based systems*

Rooted emergent aquatic macrophytes are dominant life forms in a natural wetland. In general, they produce aerial stems and leaves; they have extensive root and rhizome system. The depth penetration of the root system and thereby the exploitation of sediment volume is different for different species. Typical species of emergent aquatic macrophytes are common reed (Phragmites), cattails (Typha) and bulrush (Scirpus). All these species are morphologically adapted to growing in a water-logged sediment by virtue of large internal spaces for transportation of oxygen to the roots and rhizomes. Most such species have an extensive internal lacunal system occupying 50 - 70% of the plant volume. Oxygen is transported to the roots and rhizomes by diffusion and/or convective flow. Part of the oxygen may leak from the root system into surrounding rhizosphere, creating oxidized conditions in the otherwise anoxic sediment and stimulating both decomposition of organic matter and growth of nitrifying bacteriae.

Emergent macrophyte based systems can be constructed using three different designs.

#### 4.1.2.1 Emergent macrophyte- based system with surface flow

This is one of the oldest concepts of constructed wetlands. In this case, surface water flow is adopted in narrow and very long ditches planted mostly with bulrushes (Scirpus). The presence of submerged portions of the stems as well as litter is favoured, since they serve as substrate for attached microbial growth. This system has been used in the Netherlands for over 30 years for wastewater treatment.

#### 4.1.2.2 Emergent macrophyte - based systems with horizontal sub-surface flow

The typical design of an emergent macrophyte - based system with horizontal subsurface flow is a bed planted with reeds, generally Phragmites australis and under laid by an impermeable membrane to prevent seepage. The medium in the bed could be soil or gravel.

During the passage of effluent through the rhizosphere of the reeds, organic matter is decomposed biologically, nitrogen may be denitrified, phosphorous and heavy metals are fixed in the media. The functions of the reeds include:

- supply of oxygen to the heterotrophic micro-organisms in the rhizosphere
- increasing and stabilising the hydraulic conductivity of the media.

The experiences with such systems have indicated effective removal of SS, BOD, nitrogen and phosphorus.

Originated in Germany in the early 1970's, this system has been adopted for effluent treatment in several hundreds of cases in Germany, Denmark, the Netherlands, the USA and the UK.

#### 4.1.2.3 Emergent macrophyte - based system with vertical flow

The typical design of this system consists of several beds laid out in parallel with percolation flow and intermittent loading. During the loading period, air is forced out of the media while the drying period draws air from atmosphere to fill the pore spaces, thereby increasing the media oxygenation. Obviously, the media oxygenation is several fold, compared to a horizontal subsurface flow system, particularly since the oxygen diffusion rate in air is about 10,000 times higher than in water. The limited information available on the field application of this system indicates effective removal of BOD, SS, Phosphorus and Nitrogen.

In cold climates, since the bacterial and fungal activity is limited, the vertical flow systems are clearly preferable over horizontal subsurface flow systems. The vertical system will require much less land area and is likely to provide better quality treated effluent in cold climate. However, in warmer climate these advantages are less likely to be distinct, because higher levels of bacterial and fungal activity in such climate are likely to reduce the land area requirement for horizontal systems. One limitation with the vertical system could be the likelihood of the surface getting clogged due to SS and/or oily matter. This possibility is more or less absent in horizontal subsurface flow system.

#### *4.1.3 Submerged macrophyte - based system*

Submerged aquatic macrophyte based systems have their photosynthetic tissue entirely submerged. The morphology and ecology of the species vary from small, rosette-type, low productivity species growing only in oligotrophic waters to large eloedid-type, high-productivity species growing in eutrophic waters.

Submerged aquatic plants are capable of assimilating nutrients from polluted waters. However, these plants can survive only in oxygenated waters and therefore cannot be used in treatment of effluent with high content of biodegradable organic matter. The present limited knowledge on the system indicates that this can be used as a final polishing treatment system only.

#### *4.1.4. Algal ponds*

A variant of the systems described above, which does not generally fall under the category of wet land system is algal ponding. Generally these systems are used as a polishing treatment, also known as stabilisation ponds. In these systems, the photosynthesis action of blue-green alage, consuming carbon dioxide and liberating oxygen is used to treat organic matter. Cases of high rate algal ponding using Spirulina for the treatment of tannery effluent has been reported from South Africa.

### 4.2 Wet land system considered for the study

Based on the literature and data available about the various wet land systems mentioned above and considering the specific aspects of tannery effluent such as high salinity, relatively high suspended solids, high organic load etc., it was considered worthwhile to evaluate only emergent macrophytes with horizontal sub surface flow. It was decided to attempt one vertical flow emergent macrophytes system too.

It has been reported that this system has been successfully utilised in the treatment of domestic sewage and some industrial effluents and certain complex effluents such as landfill leachates.

### 4.3 Basic principles

The exact treatment process in a reed bed is still not fully known. It is believed that essentially the process is similar to any other biological treatment systems except that various forms of micro-organisms such as aerobic, anaerobic or anoxic may co-exist in one reed bed. It is believed that a significant portion of the micro-organisms responsible for treatment are aerobic in nature and they generally find the root structure of the reeds as the habitat. They get the atmospheric oxygen transferred by the reeds to the root structure.

The combination of various micro-organisms is expected to provide effective treatment to complex organic effluents like that from the tanneries.

## 5. REED BED AT PRESIDENCY KID LEATHER (P) LTD

### 5.1 Introduction

M/s. Presidency Kid Leather (P) Ltd. (PKL) is a leading tannery about 35 km from Chennai in Tamilnadu, India. Originally established in the year 1968, the tannery has registered impressive growth in production and export of finished leather. The speciality product of the tannery is high quality glaze kid leather.

PKL had established an effluent treatment facility as early as in 1979 and later modified the system in 1991 as per the design of M/s. Enkem Engineers Pvt. Ltd. Madras and subsequently more modifications were carried out on the technical advice of TEH Projekt, Croatia under UNIDO project, US/IND/90/244. Thereafter, the ETP has been operated regularly. UNIDO has adopted this ETP as a model unit for the region. The ETP was further improved in 1997 by adding an automatic chemical dosing system, online pH meters, flow meter etc. provided by UNIDO under US/IND/90/224.

With the technical assistance of UNIDO, PKL has set up a sophisticated environmental laboratory for proper monitoring of the effluent treatment system.  UNIDO is monitoring reuse of treated effluent for irrigation of inedible plants within the premises of the tannery.

### 5.2 Effluent treatment at the tannery

The tannery processes 4-5 tonnes of semi-finished leather to finished leather and discharges about 100-120 $m^3$ of effluent daily. The tannery has a full-fledged effluent treatment plant (ETP) with a capacity of 120 $m^3$/d.  The ETP is equipped with physico-chemical and biological treatment units.

The performance of the ETP has been generally satisfactory .The ETP has achieved BOD values as low as 10-12 mg/l in the treated effluent as against the limit of 100 mg/l.  Recently (from April, 2000) an increase in concentration of almost all parameters including BOD, COD, TDS etc. has been noted and certain parameters like COD (found fluctuating between 250 – 800 mg/l) and total dissolved solids (from 3500-8000 mg/l) remain on the higher side. The reasons for the sudden increase have been identified as some increase in production inside the tannery and reduction of wastewater volume following strict water conservation measures adopted by the tannery. The water consumption in the tannery has been reduced to 22 l/kg of raw material processed.

As the treated effluent is utilised for irrigation by the tannery, the Tamilnadu Pollution Control Board has permitted the tannery tolerance limits for COD in the treated effluent as applicable for irrigation. Nevertheless, the tannery always attempts to keep treated effluent values including COD within the tolerance limits for effluent discharged to inland surface waters.

### 5.4 Details of the reed bed system

The basic sketch of the reed bed installed at this location may be seen in Annex 1.

#### *5.4.1 Design*

The system was designed by The Solutions Centre with the following parameters and features:

| | |
|---|---|
| Flow rate of effluent | 50 $m^3$/day |
| Type of flow | Continuous |
| Basin media | Graded gravel 5 - 10 mm |
| No. of beds | 3 |
| Influent BOD (Worst Case) | 1000 mg/l |
| Effluent BOD (required) | 20 mg/l |
| Depth of media | 0.8 m |
| Slope of bed | 1 in 100 |
| Minimum porosity of media, p | 0.39 |
| Temperature dependent first order rate constant at 20$^o$ C, $K_{20}$ | 1.35 |
| Hydraulic conductivity, $K_s$ | 420 $m^3$/ $m^2$. D |
| Area of cross section | 3.9 $m^2$ per bed |
| Width (W) | 13 m |
| Length ( L) required | t'Q/Wd p = 15.72 m* |
| Length provided | 16 m |
| Overall dimensions of each bed | 16 m x 13 m x 1.2m |

**( t' – pore space retention time in days; Q – flow rate in $m^3$/d; W – width of the bed in metres; d – depth in metres; p – porosity (void index), dimensionless)*

<u>5.4.1.1 Inlet and outlet arrangements</u>

To ensure even distribution of effluent from the inlet to the bed, a HDPE pipe with orifices on its surface has been installed. Multiple inlets, to maintain uniform distribution and pressure, feed the influent. The effluent is distributed over the width of a stainless steel wire mesh gabion filled with evenly graded stones of 60 - 100 mm size. The second and third bed were not provided with the SS gabion as serial operation being the normal operation mode, most of the solids load would be taken by bed-1.

The perforations in the inlet pipe are made in such a way that adjacent perforations are at 60$^o$ angle to each other. Effectively, two lines of perforations may be seen, resembling a series of rhombii, when viewed on a two dimensional plane. The lower perforations are pointing downwards and the other perforations are pointing towards the inlet.

The outlet is similar to the inlet in construction. Provision for raising and lowering of the liquid level in the bed was made using multiple valves and pipelines. The outlet system has provision for either feeding the subsequent bed or discharge into the collection sump as desired according to the feeding requirement.

#### *5.4.2 Reed bed nursery*

At the outset, a reed bed nursery was set up in about 1200 $m^2$. The nursery was developed in March 1998 adjacent to the existing ETP of PKL. Eight varieties of reeds were grown using treated effluent for irrigation. These were: Sachharum spontaeum, Typha angustifolia, Phragmites australis, Bamboo sp, Scirpus robustus, Trema orientalis, Coix lachryma and Phragmites palar.

The purpose of developing this nursery was to verify the variety(ies) of reeds that could survive in the tannery effluent and proliferate.

The survival and propagation of reeds in the nursery after about four months may be seen in Table 1:

**Table 1: Reeds in the PKL Nursery**

| Reed variety | Nos. originally planted between 4 & 7 March 98 | Nos. survived as on 2 July 98 | Survival | Growth | Propagation |
|---|---|---|---|---|---|
| Phragmites australis | 200 | 0 | 0 | 0 | 0 |
| Bamboo sp | 80 | 32 | xx | x | 0 |
| Scirpus robustus | 120 | 70 | xx | xx | 0 |
| Sachharum spontaeum | 425 | 700 | xxx | xxxxx | Xxxx |
| Typha angustifolia | 890 | 1100 | xxx | xxx | xxxx |
| Trema orientalis | 40 | 55 | xx | x | xx |
| Coix lachryma | 20 | 3 | x | xx | 0 |
| Phragmites palar | 50 | 0 | 0 | 0 | 0 |

***Note:*** ***x - poor, xx - fair, xxx - good, xxxx-very good, xxxxx - excellent.***

### 5.5 Construction

The construction of the reed bed began on 29 May 1998 and the first and third beds were completed by 29 July 1998. The second bed was ready by 3 August 1998. Mr. Richard Daniels an international consultant and the subcontractor, TSC, were present on the occasion of re-planting reeds from the nursery in the first and third beds.

Based on the performance of reeds in the nursery, it was decided that the bed no.1 would be planted with Saccharum as the major variety, Typha mixed with Scirpus and Trema in bed no. 3 and Typha in bed no. 2. A few plants of Bamboo, Typha and Coix too were planted in bed no. 1.

### 5.6 Commissioning

The reeds were replanted from the nursery in the beds with the root structure intact. The presence of UNIDO’s international consultant, Mr. Richard Daniels, during the re-plantation of reeds from the nursery to the beds was particularly helpful in employing proper re-plantation techniques, feeding pipe modifications, finalising monitoring & feeding schedules, etc.

Bed no.1 was planted with Sachharum. The spacing between reeds was 1.0 m row wise and 0.75 m column wise. Bed no.2 was planted with a mix of Scirpus, Typha and Trema with spacing of 0.5 m. Bed no.3 was planted with Typha with 0.5 m spacing. Besides these, some small numbers of bamboo, Coix lachryma too were planted in Bed no.1.

## 5.7 Operation

The unit was put into operation on 12 August, 1998 with around 20 $m^3$/day of effluent to each bed, thus giving a total of 60 $m^3$/day of secondary treated effluent.

It was planned that the reed beds would be initially operated as parallel units and later changed to serial operation. Accordingly during the period 12 August 1998 to 31 December1998 all the three beds were operated in parallel.

For experimental purpose, treated effluent mixed with primary treated effluent (for one week at the ratio of 75:25 and later to 50:50) was admitted to bed no. 2 from 17.11.1998 to 31.12.1998, to verify the effects of feeding of primary treated effluent.

From 1 January 1999 serial operation commenced and mixing of primary treated effluent at an incremental rate with treated effluent was started. Following review with Mr. Michel Aloy, CTC and Mr. Richard Daniels, feed rate of primary treated effluent was increased in four stages; feeding at the rate of 10 $m^3$ PTE + 40 $m^3$ STE was started from 1 February 1999; it was increased to 15 $m^3$ PTE + 35 $m^3$ STE by 31 March 1999, 20 $m^3$ PTE + 30 $m^3$ STE from 15 May 1999. From 30 June 1999, the feeding was further increased to 25 $m^3$ PTE + 25 $m^3$ STE. Ultimately 30 $m^3$ PTE + 30 $m^3$ STE was reached by August 1999. This is the maximum share of PTE achieved in this reed bed.

Picture 1 shows bed no.1, picture 2 of bed no.2 and picture 3 of bed no.3 after 3 months of plantation.

***Picture 1 Bed No.1 at PKL reed bed***

***Picture 2 Bed No.2 at PKL reed bed***

*Picture 3: Bed No.3 at PKL reed bed*

## 5.8 Reeds

Contrary to the observations in the nursery, Sachharum could not survive well in the reed bed and within a span of three months, Typha had overtaken all other reeds.

The survival of reeds in PKL was observed to be as follows in chart 1:

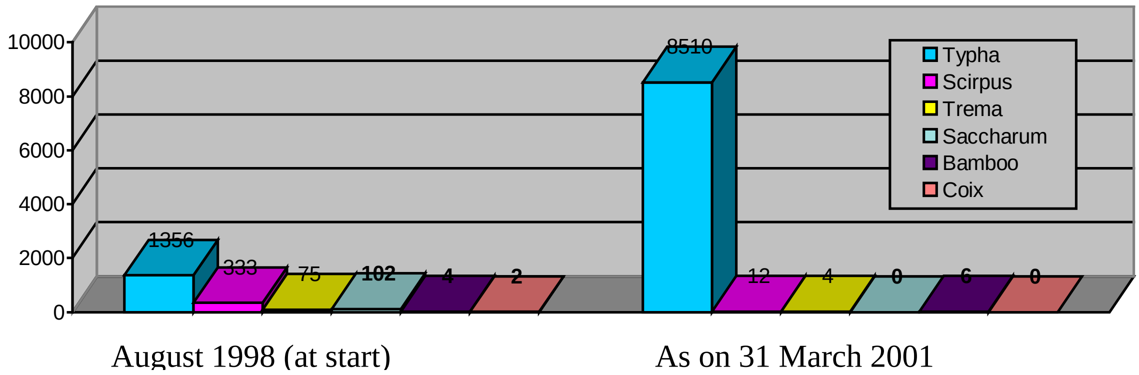


*Chart 1: Survival of reeds in PKL*

## 5.9 Performance

### *5.9.1 As a tertiary treatment system*

As planned, the reed bed was operated as a tertiary treatment system for the initial period (Aug-Dec 1998). Its performance was monitored regularly and data consolidated. Overall performance of the system for tertiary treatment is given in Table 2:

**Table 2: Performance of reed bed as a tertiary treatment system**

| Parameter | Influent | Final outlet | % reduction |
|---|---|---|---|
| pH | 7.9 | 7.2 | |
| TSS mg/l | 45 | 25 | 44 |
| TDS mg/l | 5550 | 5625 | 1.3 |
| COD mg/l | 465 | 390 | 16 |
| BOD mg/l | 28 | 14 | 50 |

### *5.9.2 Soluble BOD/COD measurement*

A doubt was raised that the efficiency obtained in the reed bed may be due to the removal of suspended solids by filtration by media and not really due to any biological action in reed beds. To verify this, soluble BOD/COD at the inlet & outlet was measured and the values obtained were not very different from total BOD/COD which established the fact that the reduction was not due to the physical filtration of solids.

Since accumulation of inorganic suspended solids in the reed bed media could eventually clog the bed, a small computation was made using data from analysis of suspended solids at the inlet and the outlet. The ratio of organic (volatile) solids versus inorganic solids in the inlet water based on continuous lab tests during the period January - March 1999 was found to be around 60:40 and that in the effluent from reed bed was 20:80. The mass balance of suspended solids in PKL reed bed is as follows:

| | |
|---|---|
| Suspended solids at the inlet | = 110 mg/l = 5.5 kg/day @ 50 $m^3$/day flow rate |
| Organic solids at the inlet | = 60% of the solids = 3.3 kg/day |
| Inorganic solids at the inlet | = 40% of the solids = 2.2 kg/day |
| Suspended solids at the outlet | = 50 mg/l = 2.5 kg/day |
| Organic solids at the outlet | = 20% of the solids = 0.5 kg/day |
| Inorganic solids at the outlet | = 80% of the solids = 2.0 kg/day |

Hence, the net organic solids accumulated/consumed in the beds = 2.8 kg/day

The net inorganic solids accumulated/consumed in the beds = 0.2 kg/day. This quantity represents approximately 3% of the total solids.

Obviously, the quantity of inorganic solids accumulating in the bed has not been high. Since any organic solids accumulating in the bed get degraded over a period of time, the possibility of clogging of the bed is not rated high.

### *5.9.3 Reed bed compared to other tertiary treatment systems*

To verify the efficacy of reed bed for tertiary treatment, it was considered best to compare it with other conventional tertiary treatment systems. For this purpose, the same inlet water let into the reed bed was collected and subjected to tertiary treatment using various proven methods. Several sets of repeated experiments were done for each trial at various dosage of chemicals. The results of these experiments are given in Table.3.

**Table 3: Reed bed as a tertiary treatment versus other tertiary treatment systems (% Reduction)**

| Parameter | Ozonation* | Activated carbon** | Chemical oxidation*** | Reed bed |
|---|---|---|---|---|
| BOD | 10-20 | 10-15 | 12-20 | 45-60 |
| COD | 5-10 | 8-10 | 4-15 | 10-15 |
| TSS | --- | 50-60 | --- | 40-50 |
| Colour | 15-20 | 20-25 | 20-25 | 10-15 |

**** Ozonation for 30 minutes to 8 hours (28 trials)***
***** Using packed bed - contact time 30 minutes to 4 hours (16 trials)***
****** Using sodium hypochlorite (50 - 500 ppm) - 18 trials and hydrogen peroxide (100-500 ppm) - 12 trials***

It is evident that, though the reduction provided by reed bed may not be very high, its performance is indeed quite comparable to that of other systems. The reduction obtained by the reed bed system at PKL therefore can be rated as quite good.

After completion of all experiments related to reed bed operation as a tertiary treatment, studies on its efficacy as a partial or total replacement of biological treatment system were taken up.

### *5.9.4 As a partial or total replacement of biological treatment*

Since no information regarding the treatability of primary treated tannery effluent (PTE) by reed bed was available, the feed rate of PTE was gradually enhanced. At first PTE was mixed with STE in the ratio of 50:50. This was done between 30 June 1999 and 30 November 1999. Thereafter feeding of 100% PTE was attempted, with re-circulation of treated effluent. The ratio of 50:50 was maintained between PTE & recirculated effluent (30 $m^3$ of PTE and 30 $m^3$ of recirculated effluent) . This pattern continued till 30 April 2000. By then, the inlet COD/BOD had risen due to changes in the production pattern. It therefore became necessary to feed the reed bed with only treated effluent for a brief period. Thereafter, a mixture of PTE and STE @ 50:50 ratio was re-introduced in June 2000 (60 $m^3$/d) and has been continued. It should be noted here that the BOD of this mixture matches the designed inlet BOD levels (900-1000 mg/l) and for all practical purposes the present feeding pattern could be regarded as identical to 100% feeding of PTE at the originally designed parameters.

The average results obtained in the PKL reed bed with feeding of primary treated effluent and secondary treated/recycled effluent is given in Table 4.

**Table 4: Performance of reed bed as a secondary treatment system**

| Parameter | Influent | Final outlet | % reduction |
|---|---|---|---|
| pH | 8.1 | 7.4 | |
| TSS mg/l | 115 | 75 | 34.8 |
| TDS mg/l | 5520 | 5640 | -2.2 |
| COD mg/l | 1677 | 751 | 55.2 |
| BOD mg/l | 651 | 146 | 77.5 |

The monthly averages of BOD/COD along with specific reduction figures have been given in Annex 2.

5.9.4.1 Analysis of performance

The performance of the reed bed as a replacement of biological treatment system can be verified only after full stabilisation, which is expected to take some more time. However the initial results with approximately 62-87% (average 81%) of BOD reduction and 42-71% (average 56.2%) of COD reduction are quite encouraging.

Doubts were expressed regarding the process of biological treatment in reed bed. It was presumed to be alike an anaerobic contact filter. In order to verify this, the inlet to reed bed was subjected to anaerobic treatment also in the lab scale anaerobic contact filter (packed with same media used for reed bed) and anaerobic activity was initiated by seeding. Then the efficiency of this contact filter was compared with that of reed bed using the same input and same hydraulic retention time.

The experiment established beyond doubt that the efficiency of reed bed is not due to anaerobic filter action, as the efficiency of the filter compared to that of the reed beds was meagre. A general comparison of efficiency of reed bed as observed is given in Table 5:

**Table 5: Reed bed vs. Conventional treatment systems (% reduction)**

| Parameter | Anaerobic treatment | Aerobic treatment | Reed bed |
|---|---|---|---|
| $BOD_5$ | 10-15 | 90-92 | 70-85 |
| COD | 8-16 | 85-90 | 50-60 |
| TSS | 10-15 | 40-50 | 30-40 |
| Colour | 45-50 | 10-15 | 5-10 |
| Nitrogen | 10-15 | 15-20 | 10-15 |
| Sulphides | $20^-$ | 80-90 | 10-15 |

***Picture 4: A view of PKL reed bed (December, 2000)***

***Reed bed No. 3***

***Reed bed No. 1 & 2***

# 6. REED BED IN CETP-VISHTEC, MELVISHARAM

## 6.1 Introduction

CETP-Vishtec is situated at Melvisharam around 120 km from Chennai. This CETP has been established for treatment of effluent discharged by 22 tanneries (out of 36 tanneries for which it has been designed) in the cluster, mostly processing raw to finished leather by vegetable tanning. The CETP employs physical, chemical & biological treatment to treat the effluent and has a good environmental laboratory.

It was decided to (1) set up a reed nursery to identify the high saline resistant reeds (as the effluent in CETP-Vishtec has > 10,000 mg/l of TDS) and (2) watch the operation of reed bed at PKL to simplify the design as much as possible and (3) implement the project with a simpler design and at a lower cost to make it a more attractive option.

## 6.2 Nursery

A nursery developed in April 1998 feeding treated effluent from day one could not survive, probably due to the sudden exposure to salinity and unsuitability of reeds brought from Kerala in geo-climatic conditions of Melvisharam and/or bad soil conditions.

The second nursery development using soil brought from outside the CETP began in July 1998. Three varieties of local reeds were selected. Initially ground water mixed with treated effluent was fed to the nursery and step-by-step, the feeding was done with increased quantity of treated effluent, to ultimately use 100% treated effluent within a months time. First three cells in the nursery were planted with Trema, Typha and Phragmites. A fourth cell was developed later for planting Scirpus brought from Kerala.

The survival/growth of reeds can be seen in chart-2.

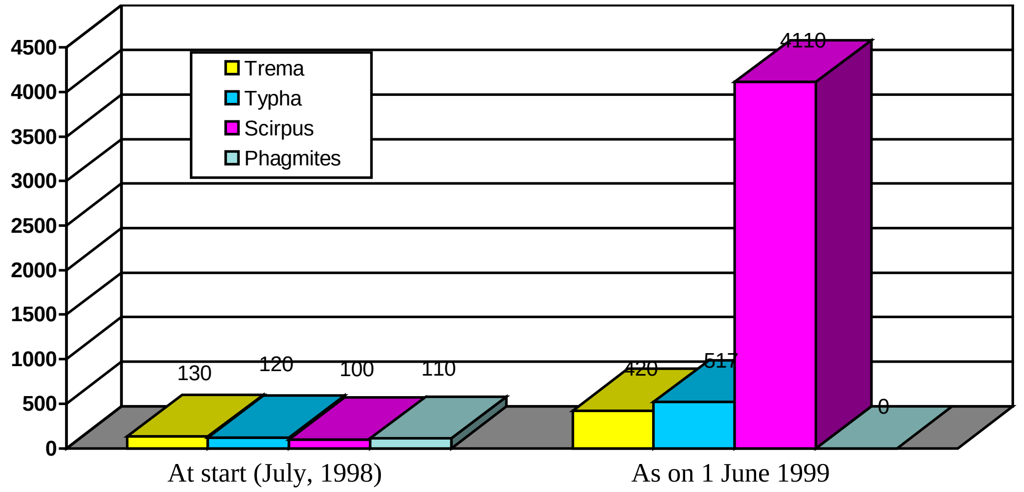


***Chart 2: Survival/growth of reeds in the nursery***

In general, all reeds except Phragmites recorded good survival and growth. Scirpus had shown prolific growth.

### 6.3 Design of reed bed

The basic sketch of the reed bed developed at CETP-Vishtec is in Annex 3, Fig 1.

#### *6.3.1 Design features*

The data used in designing the reed bed system is given below:

| | |
|---|---|
| Flow rate of effluent | 50 $m^3$/d |
| Type of flow | Continuous |
| Basin media | Sieved sand (0.5 - 1 mm size) |
| No. of beds | 1 |
| Influent BOD (worst case) | 1000 mg/l |
| Effluent BOD (required) | 30 mg/l |
| Chromium content in influent | 2 mg/l |
| Depth of media | 0.4 m |
| Porosity of media, p | 0.4 |
| Temperature dependent first order rate constant at $20^o$ C, $K_{20}$ | 1.35 |
| Hydraulic conductivity, $K_s$ | 480 $m^3$/ $m^2$. d |

Based on the above data, the system was designed as below.

| | |
|---|---|
| Area of cross section | : 13.2 $m^2$ |
| Width | : 33 m |
| Length required t'Q/Wd p | : 47.3 m |
| Length provided | : 45.0 m |

[$t^1$: pore space retention time in days ; Q: flow rate in cubic metres per day; W : width of the bed in metres ; d : depth in metres ; p : porosity {void index}, dimensionless.]

Hence a reed bed of dimensions 45 m x 33 m x 0.8 m was finalised. The single bed was designed with three compartments using LDPE sheet partitions, also to serve as baffles.

The reed bed has the following features : A bottom clay cushion of 100 mm, an impervious LDPE membrane sheet layer of 600 micron thickness and a top clay layer of 100 mm. Media used in the reed bed was sieved sand of 0.5-1 mm for a depth of 0.4 m on which the reeds were to be planted. The sides of the bed had a slope of 1 (vertical) : 3 (horizontal).

The essential differences between this and the reed bed in PKL are:

- Whereas the reed bed in PKL has a cemented base with LDPE sheet liner, the reed bed here has a clay base with LDPE sheet liner.
- The media used in PKL is pebble, sieved river sand is used as media in Vishtec
- Influent pumping was avoided and gravity feeding of effluent to reed bed is done directly from clariflocculator in Vishtec.
- Feed system simplified and gabion eliminated in Vishtec.
- A single bed in Vishtec instead of 3 separate beds in PKL.
- All three reed varieties have been planted intermixed in Vishtec.

These changes were effected based on the experience gained at PKL and other locations with the basic purpose of keeping the cost as low as feasible, without sacrificing the efficiency of the system.

### *6.3.2. Flow pattern*

The site conditions permit gravity flow for inlet from the clariflocculator. Treated effluent from reed beds is drawn to a collection sump from where it is pumped out using an ordinary centrifugal pump.

### *6.3.3 Distribution at the inlet & the outlet*

The inlet arrangement here is similar to that at PKL, i.e. a simple pipe with orifices horizontally laid at the inlet media, except that the gabion has been avoided.

The outlet pipe is similar to the inlet pipe and its discharge goes to a collection tank.

## 6.4 Construction

The implementation of the reed bed began in CETP-Vishtec by mid May 99 and excavation completed by 8 June 1999, clay bottom laid by 12 June 1999 and laying of LDPE sheet completed by 19 June 1999. The unit was subjected to leak test during the period 20 - 23 June 1999 and formation of baffles and embankment was completed by 5 July 1999. The construction of the reed bed was completed in all respects by 10 July 1999.

## 6.5 Developments during project implementation

After completion of construction, re-plantation of reeds from the nursery to the bed was done under the supervision of Mr. Anand of The Solutions Centre. The details regarding reeds transplanted are given in Table 6.

**Table 6: Reeds transplanted in the reed bed at CETP-Vishtec**

| | Reed variety | Date of plantation | Numbers planted | Total number |
|---|---|---|---|---|
| 1. | Scirpus robustus | 12 July, 1999 | 2224 | 5007 |
| 2. | Trema orientalis | 16/17 July, 1999 | 1460 | |
| 3. | Typha angustifolia | 16/17 July, 1999 | 1323 | |

As an experiment, some reeds were brought from outside (other than those from the nursery) and planted separately in the reed bed.

## 6.6 Operation & monitoring

Regular feeding of the reed bed was started from 12 July 1999 with approximately 20-30 $m^3$/day of fresh water every day. The feeding was temporarily stopped on 15-17 July to facilitate additional plantation. From 17 July onwards, approximately 30-40 $m^3$ of fresh water (with TDS 5800 mg/l and chlorides 2120 mg/l) mixed with 10-15 $m^3$ of primary treated effluent (TSS 140 mg/l, TDS 11300 mg/l, $BOD_5$ 930 mg/l, chromium 2 mg/l and COD 2300 mg/l) had been fed to the beds.

From 2 August 1999 onwards approximately 30 $m^3$/day of fresh water mixed with 30 $m^3$/day of primary treated effluent was admitted into the bed. From 16 Aug 1999, the feeding was changed to 45-60 $m^3$/day of primary treated effluent and it has been continued thereafter, except for some months when problems with hydraulics were noted.

### *6.6.1 Performance*

The average reduction of BOD in the first month (August 1999) was low, about 54%. During September 1999 it picked upto around 88%. Thereafter from October 1999 till March 2000, the performance was consistently above 90%. The initial low efficiency and gradual pick up corresponded to the growth of the reeds (and possible growth of root structure microorganisms) and it proved that the efficiency of BOD/COD removal is certainly associated with the growth and proliferation of reeds and the root zone.

The average results obtained in the Vishtec reed bed is given in Table 6.

**Table 6: Performance of reed bed**

| Parameter | Influent | Final outlet | % reduction |
|---|---|---|---|
| pH | 7.9 | 7.8 | |
| TSS mg/l | 92 | 55 | 40.2 |
| TDS mg/l | 10800 | 10225 | 0.5 |
| COD mg/l | 1466 | 522 | 64.39 |
| BOD mg/l | 658 | 121 | 81.6 |

The monthly averages of BOD/COD along with specific reduction figures have been given in Annex 4.

### *6.6.2 Analysis of performance*

Reeds procured from the locality performed better than reeds imported from far off places. The performance of a particular variety of reed in the reed bed can be significantly different from its performance in the nursery even when the same effluent is offered. The case of Scirpus robustus in this reed bed is significant.

Typha was found the best variety for treatment of effluent of various concentrations.

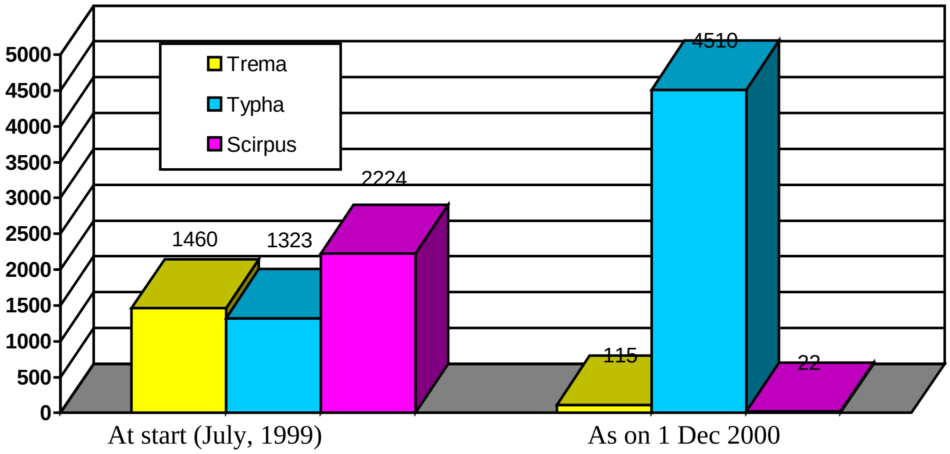


***Chart 3: Survival/growth of reeds at Vishtec reed***

By measurement of the influent and the effluent quantity in each of the beds the evapo-transpiration losses could be assessed .To counter check the correctness of the measurement, analysis of the chloride content of the influent and the effluent of each of the beds was undertaken. The reed bed hardly removes any chlorides. Relevant meteorological data like relative humidity, temperature etc., for the CETP-Vishtec was obtained from the Chennai office of the India Meteorological Department (IMD). From the meteorological data and actual evapo-transpiration rates measured, it could be inferred that the evapo-transpiration rate is a function of parameters like temperature, relative humidity, area of the reed bed, density of reeds in the bed, type of reeds (species, lacunal space in the stem of the reed variety, leaf area of the reeds etc.) and feeding rate. However, it has also seen that the climatic conditions had only a negligible impact on the performance of the reed bed. The mean evapo-transpiration rate of this reed bed was found to be 16%.

The reed bed was started with primary effluent alone. The reduction of BOD in absolute terms in the initial stages was about 54%. The system got stabilised rapidly and the second month of operation showed an absolute reduction of 89%. The rate remained consistently above 90% in the subsequent months till March 2000 when it dropped to 89.14%. Likewise, the reduction of COD was 49% in the first month, rose to 79% in the second month and was in the region of 75% thereafter. From the graphs prepared it could be seen that the BOD: COD ratio of 0.44 has resulted in the best performance as far as reduction of BOD and COD is concerned. The influent BOD had very little effect on the rate of reduction till it exceeded 800 mg/l and on specific reduction till it exceeded 750mg/l. The influent COD had only a negligible impact on the rate of reduction and specific reduction of COD.

The specific reduction of BOD ranged from 18.42 $g/m^2$/day to 62.12$g/m^2$/day. This has far exceeded the projections of the USEPA in its Manual for design of Constructed Wet lands (First edition) and subsequent Technology Update Reports (10-15 $gm/m^2$). In the case of COD reduction too, similar results were obtained.

## 6.7 Limitations noted and solutions considered

### *6.7.1 Problems noted in hydraulics*

The hydraulic conductivity of the media of the existing bed was assumed to be 480 $m^3/m^2$/d for design purposes. Initially, there was a hydraulic conductivity close to the assumed figure. However, the media started becoming smaller over a period of time thereby reducing the hydraulic conductivity and porosity. The operation of the reed bed was continued with very encouraging results till the clariflocculator in the CETP went out of order in Feb 2000, resulting in all the suspended solids entering the bed and blocking the surface of the reed bed, particularly the inlet portion. The effluent with almost 1000 mg/l suspended solids was admitted into the bed, as there was no other effluent available to ensure minimum feeding. The resultant blockage of the bed in turn had forced short-circuiting thereby reducing the hydraulic retention time and the appearance of the bed was poor.

### *6.7.2 Rectification of the bed*

As an interim measure, the clogged portion of the bed was rectified to some extent in June 2000 by replacing the top layer of sand (15 mm in the initial part of the bed and 10 mm in the remaining part) with fresh sand. Some more levelling of the bed was attempted and the beds further replanted with Typha and Trema. However, the appearance of the bed continued to be poor and further modification of the bed to ensure better conductivity had therefore been taken up in May 2001.

In order to improve the effluent distribution, new media of larger size and a distribution system made up of a channel network in the existing reed bed was considered.

It had been decided that besides better distribution system, the suggestion of Mr. Richard Daniels, International Consultant of UNIDO, based on his experiments in the UK regarding the possibility of implementing a reed bed with one-day retention time with re-circulation of the effluent, too should be attempted in the modified bed.

It was decided to have the following configuration for the modified bed:

- A provision to take care of shock loads of effluent high in SS.
- Horizontal system with larger media than that at CETP-Vishtec but less expensive than that at PKL.
- Reed varieties other than those, which had been tried earlier, including Phragmites.
- A different type of distribution of the effluent within the reed bed to prevent dead zones.
- Provision for re-circulation of treated effluent.

Since the imported variety of Phragmites australis was found to survive and propagate fairly well in the experimental reed bed at CETP-Ranitec, tissue culturing of it has been attempted for trials in the proposed reed bed, since procurement of a large quantity of these reeds would be difficult.

A bed with width of 27 m and length of 38 m was constructed accordingly.

The inlet to the bed is though a settling/polishing pond, where any excess suspended solids overflowing from the clariflocculator shall settle instead of finding its way to the bed. The peak flow to the bed is assumed as 2.5 $m^3/h$ and hence a settling pond volume of 8 $m^3$ has been assumed for a fine settling. Accordingly a settling tank in brick masonry of size 4 m (length) x 2 m (width) x 1.4 (total depth) has been made. The overflow from this tank enters the inlet channel of the reed bed. The reed bed has the following features:

- Earth excavated to 0.5 m and compacted
- Fine sand cushion of 0.2 m
- Plain cement concrete of 0.1 m
- Sidewalls and partition walls in brick masonry for a depth of 1.0 m
- Media (graded sand 3-8 mm) for a depth of 0.5 m

The improved distribution arrangement is realised by inlet and outlet channels and internal channels formed by a series of baffle walls made of brick masonry, which is made clear in the drawings. The inlet and outlet channel will be filled with pebbles of size 20 mm-30mm upto a height of 0.25 m.

The inlet channel has a dimension of 0.5 m (length) x 27.0 m (width) x 1.0 m. (total depth) Outlet channel is of 1 m (length) x 27.0 m (width) x 1.0 m (total depth). The feeding of effluent to the inlet channel is by the overflow from settling tank, distributed equally to all the compartments.

The treated effluent is pumped out from the outlet channel, which also serves as the treated effluent collection tank. One line from the pumped outlet is laid back to the inlet channel to re-circulate the treated effluent as and when desired.

The basic sketch of this modified bed too is given in Annex 3, Fig. 2.

***Picture 5: A view of reed bed at Vishtec (Dec 2000)***

# 7. OTHER EXPERIMENTAL REED BEDS

## 7.1 Reed bed at CETP-SIDCO, Ranipet

The major objective of the reed bed at CETP-SIDCO was to evaluate its performance as a colour removal unit.

### *7.1.1 Introduction*

CETP-SIDCO, situated in the SIPCOT Industrial area of Ranipet, treats effluent from tanneries processing semi-finished hides/skins to finished leather. The CETP consists of physico-chemical and biological treatment. While the treated effluent of the CETP is successful in meeting all discharge standards except the TDS, high colour in the treated effluent is a problem. Occasionally the COD values too rise above the stipulated limits.

To evaluate the suitability of using reed bed for colour/COD removal, it was planned to try a reed bed on an experimental basis. To limit the expenditure, it was planned to use an unused experimental sand filter bed available with the CETP for the purpose. The system was planned as a vertical system and batch (fill and draw) operation.

### *7.1.2 Implementation*

As mentioned earlier, the existing sand bed was converted as a vertical reed bed, operating in a fill and draw fashion on 12 August 1998. The system was put into operation with regular monitoring from August 1998.

The main experiment planned with the reed bed was to find out the optimum BOD, COD and colour reduction and the optimum hydraulic retention time to achieve the mandatory COD limit of 250 mg/l.

### *7.1.3 Details*

The converted bed has the following specifications:

Dimensions: 11 m x 5 m x 1.15 m, Media: 0.2 m gravel (10-20 mm size) in the bottom and 0.95 m sieved sand (0.5-1 mm size) on top.

### *7.1.4 Reeds*

The reed bed was planted with Typha, Phragmites (local species) and Scirpus. The survival/ propagation of Typha was found to be better than of Scirpus while the Phragmites could not survive.

The data regarding survival and growth of reeds may be seen in chart 3.

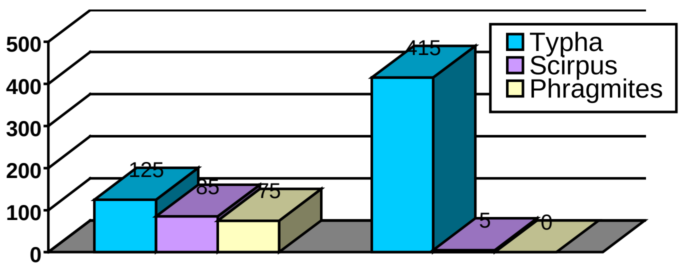


***Chart 3: Reeds in CETP-Sidco***

At start (July 1998) As on 31 December 2000

### *7.1.5 Experiments*

The system had produced good BOD/COD reduction and very good reduction in colour. When operated with lower retention times too, the system produced good performance. Step-by-step the feeding was increased to reduce the hydraulic retention time from five to 2.5 days. The overall performance of the system in terms of BOD/COD can be seen in chart 4 & 5:

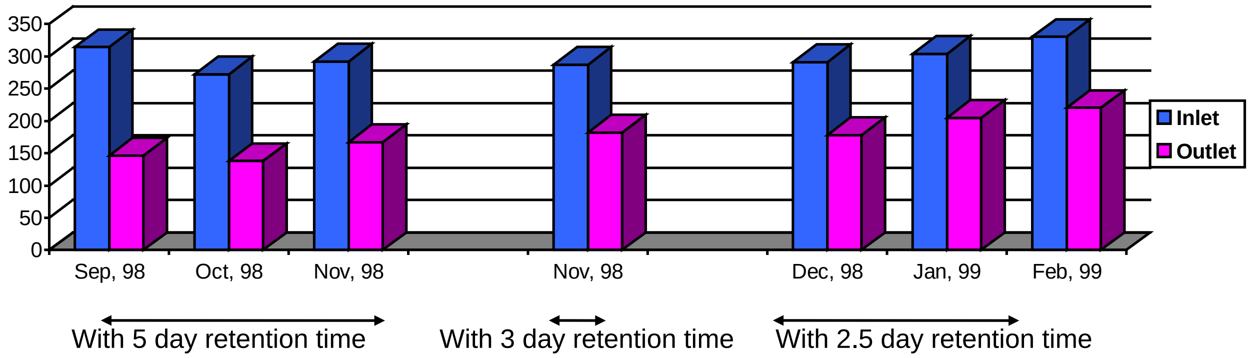


***Chart 4: COD values at the inlet & the outlet of reed bed***

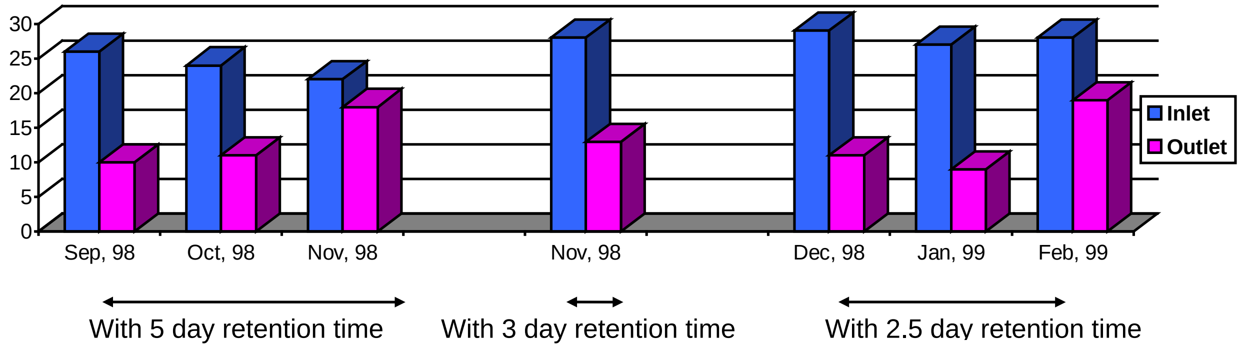


***Chart 5: BOD values at the inlet & the outlet of reed bed***

When the feeding was increased to 12.5 $m^3$/day (equivalent to 2 days retention time), the system performance steadily declined and at one point, collapsed. Immediate withdrawal of feeding increase restored the performance to some extent. This change, can be seen in chart 6:

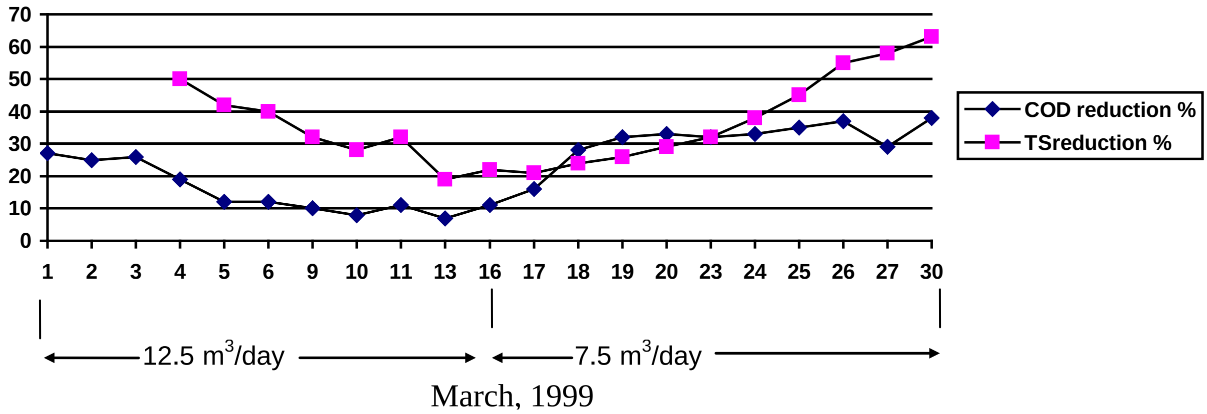


***Chart 6: COD reduction at reduced detention***

From 1 April, 1999 the system has been operated with 7.5 $m^3$/day (equivalent to 3 days retention time) with more or less consistent performance as seen in Table 6 (average till Dec 2000).

**Table 6: Average performance of the system at CETP-SIDCO**

| Parameter | Feed water | Final outlet | % reduction |
|---|---|---|---|
| pH | 7.3 | 7.6 | --- |
| TSS mg/l | 135 | 65 | 52 |
| Colour Pt- Co unit | 765 | 85 | 88 |
| TDS mg/l | 4750 | 4355 | 8 |
| COD mg/l | 345 | 228 | 40 |
| BOD mg/l | 27 | 13 | 52 |

Since all data required by UNIDO has been collected and consolidated, no further activity is carried out by UNIDO here. However, the CETP management is using this facility as a demonstration project.

### *7.1.6 Evaluation*

To verify the efficacy of reed bed for tertiary treatment, the same inlet water let into the reed bed was collected and subjected to tertiary treatment using various methods. Several sets of repeated experiments were done for each trial at various dosages. The results of these experiments are given in Table 7.

**Table 7: Reed bed vs. conventional tertiary treatment systems (% Reduction)**

| # | Parameter | Activated carbon* | Chemical oxidation** | Chemical precipitation*** | Reed bed |
|---|---|---|---|---|---|
| 1. | BOD | 50-60 | 12-20 | 15-20 | 60-70 |
| 2. | COD | 60-65 | 15-20 | 20-25 | 50-60 |
| 3. | TSS | 50-60 | --- | 70-80 | 40-50 |
| 4. | COLOUR | 40-50 | 10-15 | 40-50 | 30-40 |

** Using powdered carbon added to aeration tank MLSS - 0.2-5 g/l - 16 trials, packed bed - contact time 30 minutes to 4 hours- 4 trials*
*** Using sodium hypo chlorite (50 - 500 ppm) - 12 trials and hydrogen peroxide (100-500 ppm) - 6 trials*
**** Alum dosage (100-250 mg/l), Lime (100-300 mg/l) and PE (1-2 ppm) - 26 trials*

*Note: The values shown above for reed bed are based on 5-day retention time.*

***Picture 6: Reed bed developed at CETP-SIDCO***

***Picture 7: Clarity of treated effluent from the reed bed at CETP-SIDCO***

## 7.2 Reed bed at CETP-Ranitec, Ranipet

The specific objective of the reed bed at CETP-Ranitec was to evaluate it as tertiary treatment for reduction of TSS, COD and colour. The flow pattern was horizontal and the feeding, continuous.

### *7.2.1 Introduction*

CETP-Ranitec is situated at Ranipet in V. C. Mottur in Walajah taluk. The CETP has been established for the treatment of effluent discharged by 76 tanneries in the cluster, mostly processing raw hides/skins to finished leather, largely by vegetable tanning. The CETP employs physical, chemical & biological treatment and a tertiary treatment unit to treat the effluent. The purpose of tertiary treatment is reduction of colour and BOD/COD. Though the efficiency of this tertiary treatment is generally satisfactory, the cost of operation has been prohibitively high. The experimental reed bed unit was established in this context.

### *7.2.2 First set of experiments*

A pilot scale experiment was taken up in July, 1998 with a small reed bed of dimensions 5 m x 8 m x 0.5 m and construction with 200 micron LDPE sheet in the bottom, 10 cm gravel (10-20 mm size) and 0.40 m sieved sand (0.5-1 mm size) on top.

The reed bed was planted with Typha, Phragmites (local species), Scirpus and Trema. The survival/propagation of Typha was found to be better than that of Scirpus while the Phragmites could not survive.

The small bed was made as a horizontal reed bed, operating with continuous feeding. The feeding to the bed was started by 03 August 1998. The system was put into operation with regular monitoring from September 1998.

Main experiments planned with the reed bed were to find out the optimum BOD, COD and colour reduction.

### *7.2.3 Performance of the experimental bed*

The performance of the experimental bed was really good and the average efficiency obtained during its one year of operation was as provided in Table 8:

**Table 8: Operational efficiency of reed bed at CETP-Ranitec (with 5 day retention time)**

| # | Parameter | Influent | Treated effluent | % reduction |
|---|---|---|---|---|
| 1. | pH | 7.1 | 7.0 | --- |
| 2. | COD mg/l | 304 | 165 | 46 |
| 3. | BOD mg/l | 24 | 9 | 62 |

### *7.2.4 Fill and draw system*

To check the impact of the feeding pattern on the performance of reed bed, the continuous feeding maintained from the beginning till end of December 1998 was changed to fill and draw system for a month from 1 January to 3 February 1999. The performance reported during this period is given in Table 9.

**Table 9: Performance of reed bed using fill and draw system during the period 01 January to 03 February 1999**

| # | Parameter | Influent | Treated effluent | % reduction |
|---|---|---|---|---|
| 1. | pH | 7.1 | 7.1 | |

| | | | | |
|---|---|---|---|---|
| 2. | COD mg/l | 385 | 260 | 26 |
| 3. | BOD mg/l | 19 | 14 | 27 |

As the performance came down by feeding modification to fill and draw system and the trend indicated that the system performance could deteriorate further, it was decided to revert to continuous feeding. Nevertheless, though very short, the experiment with fill and draw system was informative and useful.

### *7.2.5 Modifications in feeding rate*

As in the case of SIDCO, in order to find out the changes in efficiency of reed bed, the retention time was reduced to 3 days from the 5 days originally maintained and the performance of the system observed during this period is given in Table 10.

**Table 10: Performance of the reed bed after reducing the retention time to 3 days**

| # | Parameter | Influent | Treated effluent | % reduction |
|---|---|---|---|---|
| 1. | pH | 7.0 | 7.2 | |
| 2. | COD mg/l | 388 | 235 | 39.4 |
| 3. | BOD mg/l | 26 | 12 | 53.8 |

### *7.2.6 Construction of a larger bed*

Encouraged by the performance of the experimental bed, Ranitec constructed a relatively larger bed with dimensions 12 m x 7 m x 0.7 m in June 1999. The construction was done by excavation of the area, clay puddling and 0.5 m of sand as the media. The sealing by LDPE sheet was not attempted, as the bed was treating only treated effluent.

Three types of reeds (Trema, Typha and Scirpus) were planted. The Scirpus could not survive; where as the other two reeds have grown well. The Typha grew well initially but subsided after some time and Trema had grown very well.

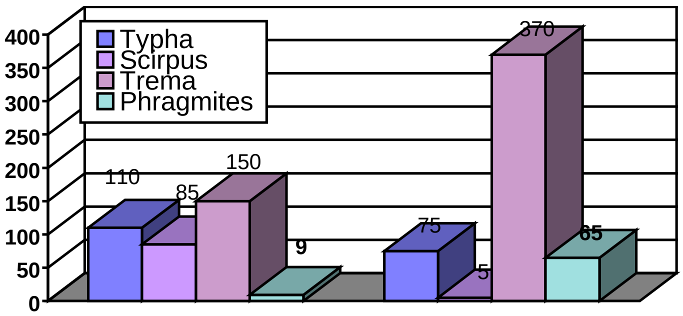


***Chart 7: Reeds at CETP-Ranitec***

At start (June 1999)   As on 31 December 2000

Later, in association with a company by name Thermax, some Phragmites developed by tissue culture from the original Australian species was planted in this small bed. The nine numbers of the Phragmites planted during May 2000 have grown very well and multiplied into more than 500 reeds now.

### *7.2.7 Performance*

The system produced good BOD/COD reduction and very good reduction in colour. When operated with lower retention times too, the system produced good performance. The overall performance of the system at stabilised state at 5 day detention time can be seen in the Table 11 below:

**Table 11: Performance of the larger bed (5 day retention time)**

| # | Parameter | Influent | Treated effluent | % reduction |
|---|---|---|---|---|
| 1. | pH | 7.1 | 7.2 | |
| 2. | COD mg/l | 388 | 262 | 32.4 |
| 3. | BOD mg/l | 29 | 16 | 44.8 |

### *7.2.8 Evaluation*

To compare the efficacy of the reed bed as a replacement of the existing tertiary treatment, the efficiency reported by existing tertiary treatment was juxtaposed with the reed bed performance. Further, the same inlet water let into the reed bed was collected and subjected to tertiary treatment using chemical oxidation. The results of these experiments are given in Table 12.

**Table 12: Reed bed vs. Conventional tertiary treatment systems (% Reduction)**

| Parameter | Chemical precipitation* | Chemical oxidation** | Reed bed |
|---|---|---|---|
| BOD | 35-55 | 15-25 | 40-50 |
| COD | 45-65 | 35-40 | 30-40 |
| TSS | 55-70 | --- | 40-50 |
| Colour | 25-40 | 35-40 | 50-55 |

* *Result obtained from existing tertiary treatment - two year data*
** *Using sodium hypo chlorite (50 - 500 ppm) - 5 trials*

### *7.2.9 Present Status*

The monitoring of the reed bed by Ranitec continues with parameters such as flow rates, characteristics of inlet and outlet such as pH, TSS, TDS, BOD, COD and TKN monitored on a daily basis.

Since all data required by UNIDO has been collected and consolidated, no further activity is foreseen here. However the CETP management is maintaining it as a demonstration unit.

***Picture 8: Latest view of reed bed at Ranitec (Dec 2000)***

***Picture 9: Phragmites australis at CETP-Ranitec***

## 8. OVERALL ANALYSIS OF THE PERFORMANCE OF PILOT DEMONSTRATION UNITS

### 8.1 Features

A comparison of the key features of reed bed projects established is given in Table 13.

**Table 13: Reed beds in Tamil Nadu**

| Project | Objective | Type of effluent | Flow pattern | Type of feeding | Media used | Operational from |
|---|---|---|---|---|---|---|
| **PKL** | 1) Evaluation of unit as a tertiary treatment unit, mainly colour & COD removal<br>2) As a replacement of biological treatment for BOD/COD removal | Wet blue - finish | Horizontal | Continuous | Pebbles | August, 1998 |
| **Sidco** | Evaluation of the system as a tertiary treatment, mainly colour removal | Wet blue - finish | Vertical | Fill & draw | Sand | August, 1998 |
| **Ranitec** | Evaluation of the system as a tertiary treatment, mainly colour & COD | Raw-finish (EI) | Horizontal | Continuous | Sand | August, 1998 |
| **Vishtec** | As a replacement of biological treatment, BOD/ COD removal | Raw-finish (EI) | Horizontal | Continuous | Sand | July, 99 |

### 8.2. Reeds

- Eight reed varieties were tried in the reed beds viz. Typha angustifolia, Sachharum spontaneum, Scirpus robustus, Trema orientalis, Coix Lachryma, Phragmites australis, Bamboo sp. & Phragmites palar.
- Contrary to the expectations, the most common reed viz., Phragmites did not survive in any of the reed beds established. The Sachharum which had grown well in the nursery (established prior to construction of reed bed) did not survive in the reed bed in PKL.
- However, the Phragmite reeds supplied by Thermax had grown very well in Ranitec, which indicated that the non-survival of Phragmites might have more to do with the genetic properties of the plants selected.
- Some distinct changes like somewhat stunted growth of reeds in November - December (Winter) and much better growth & proliferation from February onwards (summer) were observed in PKL & Vishtec.
- Typha could survive well in all the pilot units.
- It has been noted that while Typha and Phragmites survive and grow better in flooded environment, Trema grows well in relatively dry areas. This is in line with the observations of hydroperiod of these species under natural conditions.
- The reeds were kept flooded during daytime, as it was observed that the reeds suffered when only subsurface flow was maintained all the time due to high temperature of the media in summer.
- Original assumptions predicted the requirement of the thinning/trimming of reeds once in 4-5 years. It has been observed that at least for Typha, trimming is required once in 3-4 months.
- Some reeds such as Trema, Coix and Sachharum which initially had shown good survival rate in PKL, had all slowly died.

In general, the survival/growth of reeds observed are as follows:

| **Item** | **PKL** | **Sidco** | **Ranitec** | **Vishtec** |
|---|---|---|---|---|
| Type of effluent | Wet blue – finish | Wet blue – finish | Raw-finish (EI) | Raw-finish (EI) |
| TDS, mg/l | 4000-6000 | 3000-4500 | 10000-12000 | 10000-11000 |
| | | | | |
| Typha | **** | *** | *** | *** |
| Trema | * | Not tried | *** | * |
| Scirpus | * | * | ** | * |

| | | | | |
|---|---|---|---|---|
| Phragmites Australis | 0 | 0 | **** | 0 |
| Bamboo | * | Not tried | Not tried | Not tried |
| Sachharum | * | Not tried | Not tried | Not tried |
| Coix | * | Not tried | Not tried | Not tried |

*(* poor, ** fair *** good / very good **** excellent )*

### 8.3 Performance

**Reed bed as a tertiary treatment system**

- A small reduction in COD/ $BOD_5$ of 10-15% was obtained with 5 day hydraulic retention time in the reed bed at PKL. Good reduction in turbidity (50-60% measured as SSU) and (10-15%) colour measured as Pt-Co units was obtained.
- The small reed bed at CETP-SIDCO (converted from an inoperational sand filter bed) provided better $BOD_5$ /COD removals. Approximate reduction in $BOD_5$ /COD was 60% @ 5 days HRT, 50-55% @ 3.5 days HRT and 40-50% @ 2.5-3 days. Reducing detention time to less than 2.5 days resulted in a collapse of the system. The reduction in colour measured as Pt-Co units was 60%, 40% and 40% respectively.
- At the small reed bed at CETP-Ranitec approximately 50-60% reduction in $BOD_5$ /COD at 5-day detention time and around 40% reduction in $BOD_5$ /COD at 3.5-4 days detention time was obtained. Good removal of turbidity (60-70%) was obtained using the system at both feeding rates. For a trial, the feeding pattern was changed from continuous feeding to fill and draw, which had resulted in a drastic reduction of performance.
- The removal of nitrogen was around 10-15% in PKL, 20-25% in CETP-SIDCO and 25-35% in CETP-Ranitec.

**Analysis:**

- The rather low efficiency of the reed bed at PKL while treating secondary treated effluent was not unexpected, since the effluent had already gone through an elaborate chemical & biological treatment. The low $BOD_5$ already revealed the low biodegradability of the residual COD in the effluent. The expectations that further COD removal even at low $BOD_5$ levels would be possible was not realised in PKL.
- The residual COD in PKL was previously found unreactive to other chemical oxidants like peroxide, ozone etc. and found unabsorbed in activated carbon. The residual COD in this plant was indeed really tough.
- The reed bed at CETP-SIDCO could achieve good COD removal at even low $BOD_5$ levels. Unlike PKL, this COD was found to be oxidisable and absorbable in activated carbon, but this was not practised due to high running cost. Its removal in reed bed is therefore logical. Further, though it is not proven beyond doubt, one can assume that the media used in the reed bed at CETP-SIDCO (sieved sand) facilitated better removal of pollutants.
- The performance of the reed bed at CETP-Ranitec was more or less similar to that of CETP-SIDCO. Two important lessons learnt from Ranitec are: (1) Continuous feeding is more efficient than fill and draw system and (2) Salinity of effluent does not affect the performance of the reed, though it may have some relevance to survival of reeds.

**Reed bed as a secondary (biological) treatment system**

**At PKL**

- The reduction of $BOD_5$ ranged between 62% and 87% in absolute terms during the project period. The influent $BOD_5$ varied from 227 mg/l to 1117 mg/l depending on the quality of primary effluent as well as the composition of the feed.
- The overall reduction obtained at PKL is given in Annex 2.
- The reduction of $BOD_5$ and COD against the various $BOD_5$ : COD ratios have been presented in charts 8 & 9.
- The process efficiency vis-à-vis the influent $BOD_5$ is given in chart 10. It was observed that the influent $BOD_5$ had some bearing on the rate of reduction. The reduction of COD vis-à-vis influent COD is given in chart 11.
- Specific reduction of $BOD_5$ and COD against the $BOD_5$ : COD ratio is presented in charts 12 & 13 respectively.
- The impact of the influent $BOD_5$ can be observed in the specific reduction as presented in chart 14. Here the specific reduction was found to increase with the influent $BOD_5$ and decrease steadily when the influent $BOD_5$ exceeded 800mg/l.
- Specific reduction of COD against influent COD is presented in chart 15. However, unlike in case of $BOD_5$ this does not provide any trend in this direction.

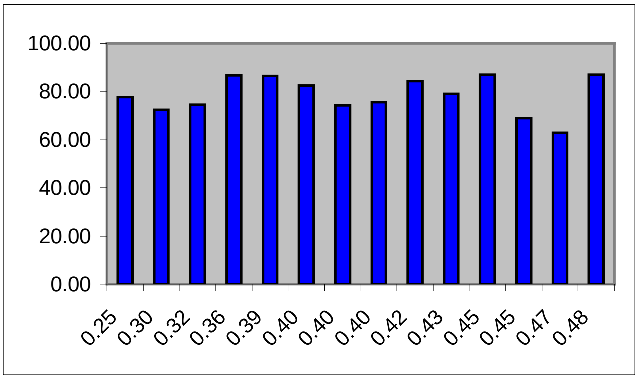


*Chart 8: Rate of reduction of $BOD_5$ Vs $BOD_5$ :COD ratio*

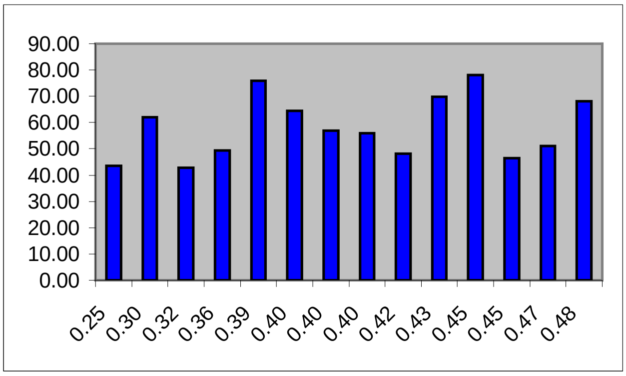


*Chart 9: Rate of reduction of COD Vs $BOD_5$ :COD ratio*

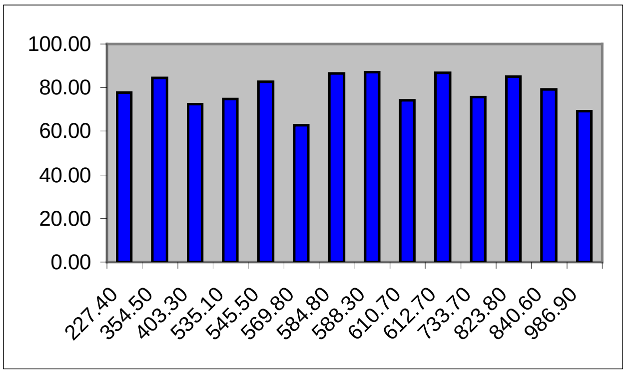


*Chart 10: Rate of reduction of $BOD_5$ against influent $BOD_5$*

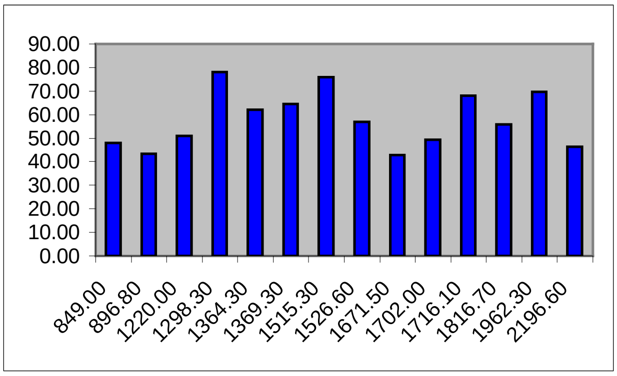


*Chart 11: Rate of reduction of COD against influent COD*

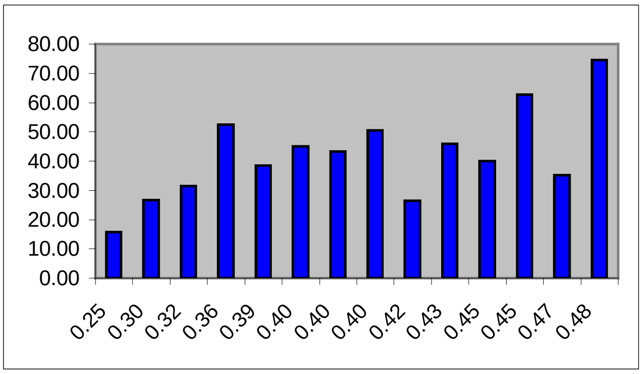


*Chart 12: Specific reduction of $BOD_5$ against $BOD_5$ :COD ratio*

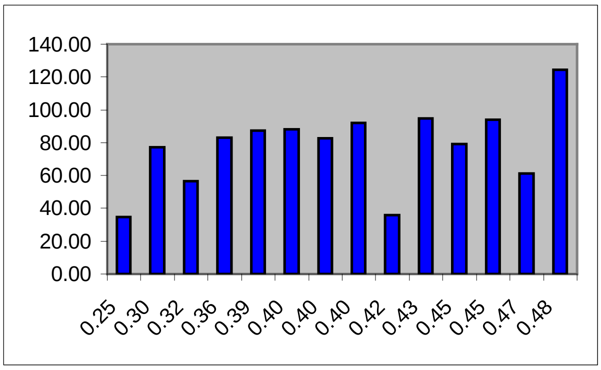


*Chart 13: Specific reduction of COD against $BOD_5$ :COD ratio*

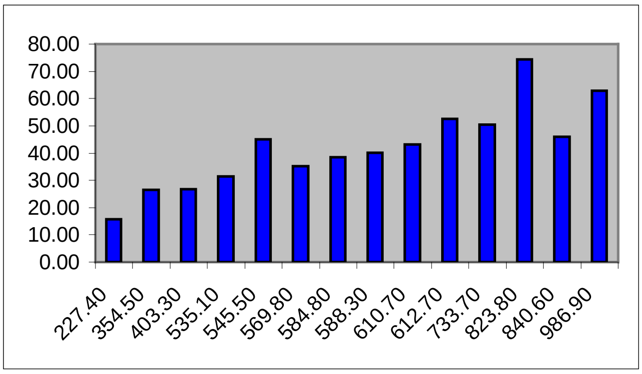


*Chart 14: Specific reduction of $BOD_5$ against influent $BOD_5$*

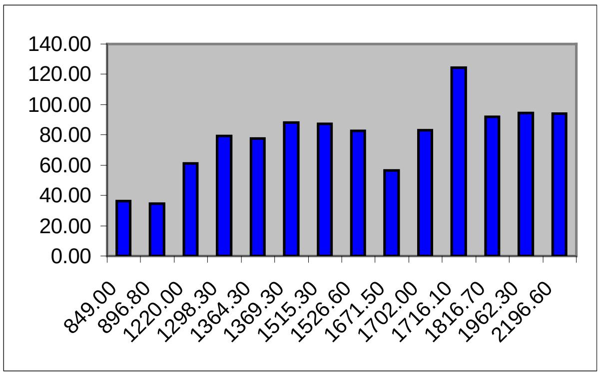


*Chart 15: Specific reduction of COD against influent COD*

***Note: All the above specific reduction values are in g/m$^2$ .***

- Overall, the performance has been in line with expectations.
- It may be noted that even though only a mixture of primary and secondary effluent was offered to the reed bed, the actual influent $BOD_5$ level had been close to the design conditions.
- The reed bed experiment was successful enough to handle the type of effluent as designed. However, the effluent from the reed bed was having a mean $BOD_5$ of 147 mg/l if the entire fourteen months from February 1999 to March 2000 were considered.
- This also shows that the design concept used, i.e., considering the $BOD_5$ of the offer alone with ambient temperature is insufficient for designing such a system. The past experience with effluents from other industries as well as sewage had been the only data to rely on for designing the system. This in turn also indicates that in the case of tannery effluent, particularly for tanneries processing wet blue to finished leather, there are other factors (such as high COD: $BOD_5$ ratio, low degradability of the COD etc.) influencing the performance of the system. Since the climatic conditions were found to be of little significance on the performance of the system it can be said that the various components of the effluent fed to the reed bed influence its performance.

(b) At CETP-Vishtec

- The monthly averages of $BOD_5$ /COD along with specific reduction figures have been given in Annex 4.
- The reed bed was started with primary effluent. The reduction of $BOD_5$ in absolute terms in the initial stages was about 54%. The system got stabilised rapidly and the second month of operation showed an absolute reduction of 89%. The rate remained consistently above

90% in the subsequent months till March 2000 when it dropped to 89.74%. The mean reduction of $BOD_5$ during the monitoring period was 87.31 %.

- Likewise, the reduction of COD was 49% in the first month, rose to 79% in the second month and was in the region of 75% subsequently. The mean reduction of COD during the monitoring period was 74.9%.
- From the graphs prepared it could be seen that the $BOD_5$ :COD ratio of 0.44 had resulted in the best performance as far as reduction of $BOD_5$ and COD. The $BOD_5$ :COD ratio remained in this range initially. The problems in the primary treatment could be the reason for the subsequent reduction in the $BOD_5$ :COD ratio.
- The influent $BOD_5$ was found to have very little effect on the rate of reduction till it exceeded 800mg/l and on specific reduction till it exceeded 750mg/l. From this it could be inferred that for best results, the influent $BOD_5$ is to be maintained at less than 750 mg/l.
- Charts 16 to 23 present the performance of the reed bed in terms of removal of $BOD_5$ & COD under various conditions.

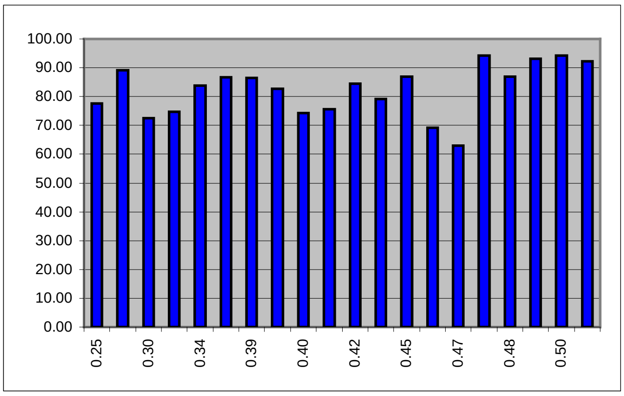


*Chart 16: Rate of reduction of $BOD_5$ Vs $BOD_5$ :COD ratio*

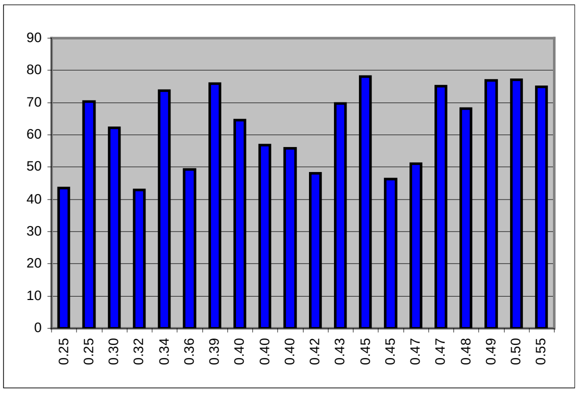


*Chart 17: Rate of reduction of COD Vs $BOD_5$ :COD ratio*

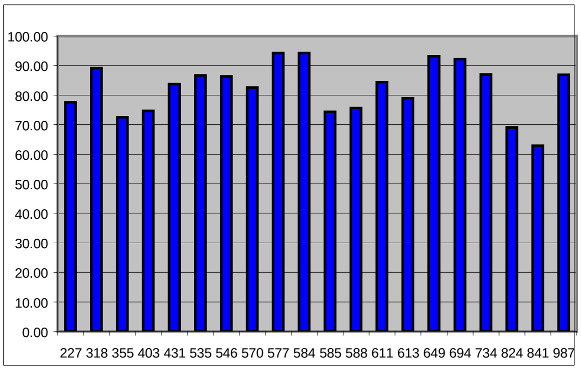


*Chart 18: Rate of reduction of $BOD_5$ against influent $BOD_5$*

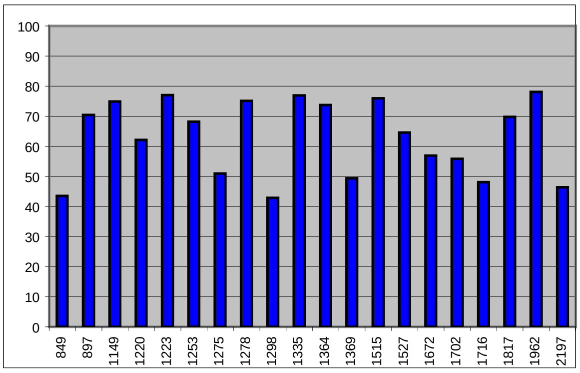


*Chart 19: Rate of reduction of COD against influent COD*

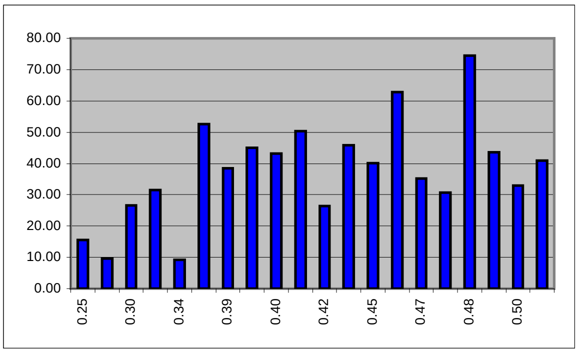


*Chart 20: Specific reduction of $BOD_5$ Vs $BOD_5$ :COD ratio*

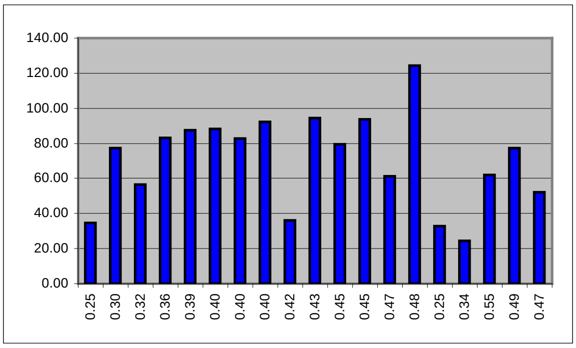


*Chart 21: Specific reduction of COD Vs $BOD_5$ :COD ratio*

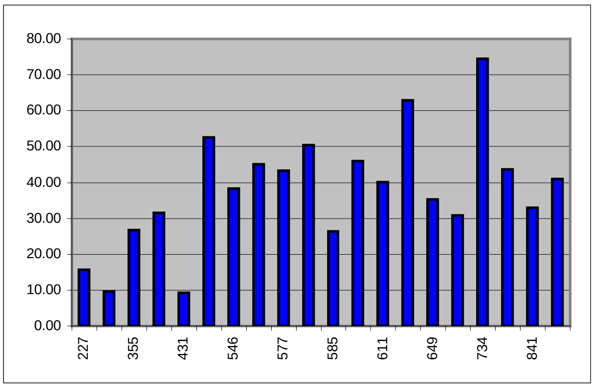


*Chart 22: Specific reduction of $BOD_5$ Vs influent $BOD_5$*

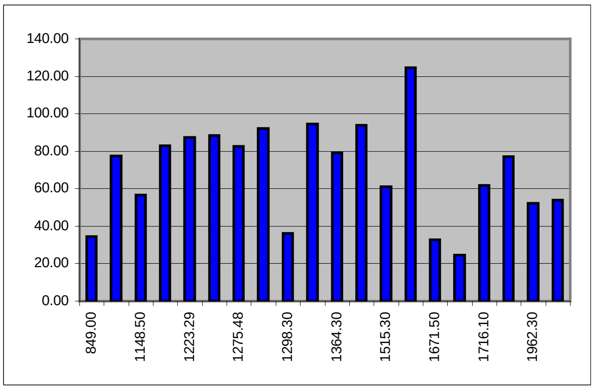


*Chart 23: Specific reduction of COD Vs influent COD*

***Note: All the above specific reduction values are in g/m$^2$.***

- The specific reduction of $BOD_5$ ranged from 23.47g/m$^2$ /d to 62.12 g/m$^2$ /d with an average of 45.21 g/m$^2$ /d. This has far exceeded the projection by the United States Environment Protection Agency (USEPA) in the Manual for design of Constructed Wet lands (First edition) and the subsequent Technology Update Reports.
- In the case of COD reduction also, similar results were achieved. The mean specific reduction of COD during the monitoring period was found to be 101 g/m$^2$ /d. The minimum specific reduction observed was 68.54 g/m$^2$ /d during the month of March 2000 when the quality of the effluent fed to the reed bed had deteriorated due to high SS. The maximum specific reduction observed was in the month of January 2000 at 146.26 g/m$^2$ /d.
- The reed bed was functioning smoothly till some mechanical problems in the clariflocculator resulted in the deterioration of the quality of the effluent fed. The suspended solids content, which usually was in the range of 150 mg/l to 200 mg/l, increased upto 1000 mg/l. This resulted in much decreased hydraulic conductivity and consequent measures to replace the top layer of the media.

### 8.4 Other observations

- In PKL, evapo-transpiration of 16-20% was obtained in summer and 8-12% in winter which is equivalent to 14.4 l/m$^2$ and 8 l/m$^2$ @ 625 m$^2$ bed area. Against the reported normal evaporation rate of 4-7 l/m$^2$ in open surface observed in PKL during comparison trials, this evapo-transpiration rate is higher.
- The mean evapo-transpiration observed in Vishtec is 16%, which corresponds to 5.4 l/m$^2$.
- Since the evapo-transpiration rate corresponds to the reported evaporation rate in normal wet land systems, it is assumed that the entire water loss across the reed bed is due to evapo-transpiration only and not due to any percolation.
- During the early stages of the reed bed operation in PKL, a lot of wild life such as butterflies, dragonflies, frogs and snakes was seen in the beds. However, when the feeding of primary treated effluent started, all these disappeared. Of late, some flies and frogs are seen in second and third beds of PKL.
- No appreciable presence of wild life except butterflies was noted in the other small reed bed projects.

## 9. COST

### 9.1 Installation cost

The reed bed established at PKL, owing to its robust construction, overcautious design and extra provisions for monitoring etc. is quite expensive. The installation cost was around US $ 1000 / $m^3$ as against the average installation cost of US $ 700-800/$m^3$ for conventional biological treatment.

The more basic reed bed constructed at Vishtec cost US $ 300/$m^3$.

### 9.2 Operational cost

The operational cost per day observed in the two reed beds can be seen below:

| Item | PKL | | Vishtec | |
|---|---|---|---|---|
| | In INR | In US $ | In INR | In US $ |
| Labour | 40 | 0.87 | 40 | 0.87 |
| Power | 144 | 3.13 | 96 | 2.09 |
| Monitoring | 36 | 0.78 | 36 | 0.78 |
| Harvesting | 5 | 0.11 | 5 | 0.11 |
| Miscellaneous | 25 | 0.54 | 25 | 0.54 |
| Depreciation/finance costs | 330 | 7.17 | 100 | 2.17 |
| Total | 580 | 12.61 | 302 | 6.57 |
| Treatment cost per $m^3$ | 11.6 | 0.25 | 6.04 | 0.13 |

## 10. CONCLUSIONS

Based on the results obtained so far, the following tentative conclusions are appropriate:

- As a tertiary treatment, the reed bed system with sieved sand (preferably of size 2 to 5 mm) as the medium and continuous feeding is appropriate for obtaining 50-60% organic removal efficiency (better than any other common tertiary treatment system) with better colour and turbidity removal. The minimum retention required is 3 days.
- Salinity may not be a problem for survival of reeds or operation of reed beds.
- As a replacement of biological treatment, as the system has been operating only for about two years, it is yet early to conclude its viability but the initial indications are quite encouraging.

## 11.FUTURE

1. The monitoring of the reed bed at ETP, PKL will be continued by the management to determine consistency of performance, occurrence/repetition of operational problems including clogging.
2. The reed bed at CETP-Vishtec has yielded valuable lessons. However hydraulic conductivity of the bed has been adversely affected leading to emergence of some dead zones. Besides it has been felt that provision for re-circulation of effluent with a view to reduce retention period needs to be incorporated to verify the impact of recirculation. A more even distribution of effluent all over the bed and protection to bed against shock loading of suspended solids are considered necessary. Accordingly the existing bed may be modified to introduce the above features. This will help finalise design features of a robust, cost-effective, reed bed design for future. At Annex 5 a conceptual design is provided for 50 $m^3$/d capacity ETP, with a reed bed for biological treatment of effluent.

3. CETP-Ranitec, encouraged by the results so far, is planning a bed with a capacity of 100 $m^3$/d, as a pilot unit, to eventually put up a large-scale reed bed as tertiary treatment for its entire capacity of 4000 $m^3$/day, with its own resources.

4. All data collection on operation of reed beds as tertiary treatment is over. Operation & monitoring of the small reed beds in CETP-SIDCO & CETP-Ranitec have been left to the respective CETP management.

5. Based on the results achieved so far, it is foreseen that there will be excellent scope for wider replication of this technology in various countries of the South & South East Asia region & possibly South America and Africa too where availability of land may not be a constraint**.**


## ACKNOWLEDGEMENT

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7. Tamilnadu Pollution Control Board, Chennai, Tamilnadu, India.


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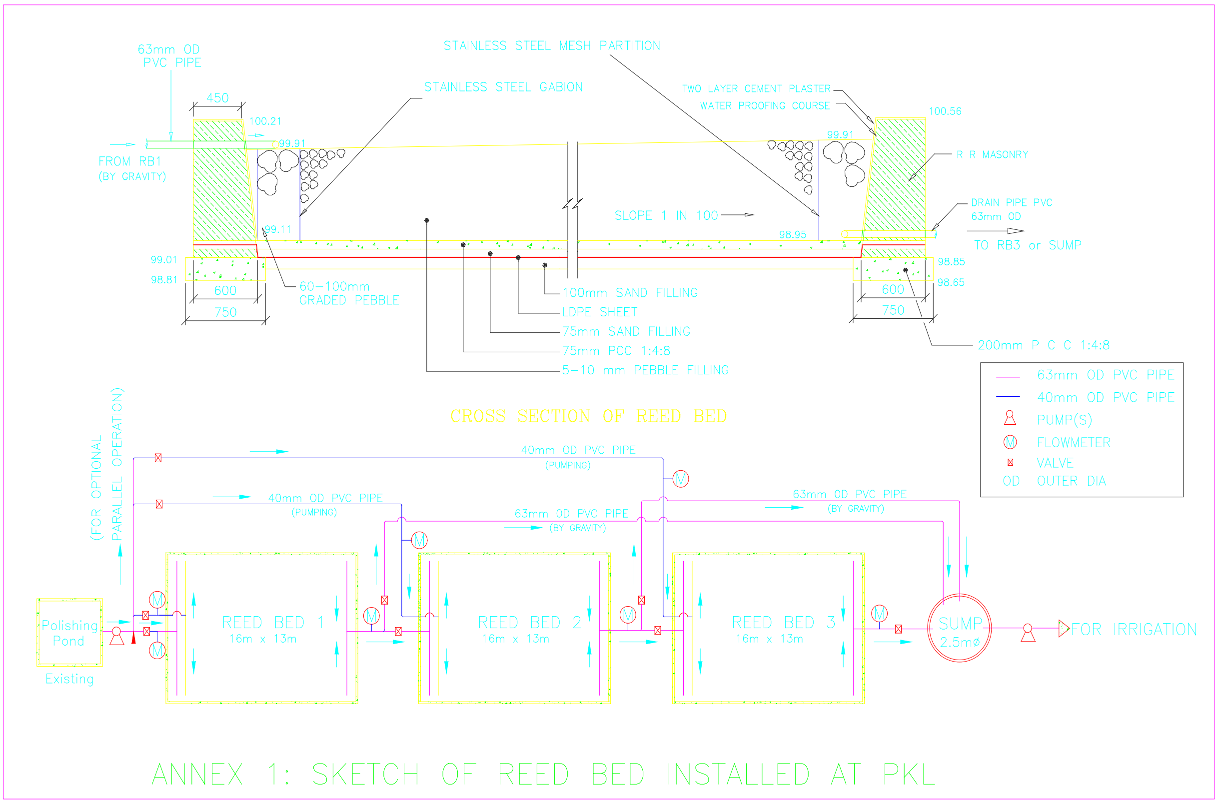
1. Enhanced root-zone systems: cost effective alternative for the biological treatment of tannery effluents: Richard Daniels, United Kingdom, paper presented in the XXVI IULTCS Congress, Cape Town, South Africa, March 2001.
2. High rate algal ponding: Johan P. Bernard, LIRI, South Africa, paper presented on Regional Workshop on design, operation and maintenance of effluent treatment plant for tanneries, Chennai, India, October 1997.

# Annex 1
# The basic sketch of the reed bed installed at PKL



# PERFORMANCE ANALYSIS OF THE REED BED SYSTEM AT PKL

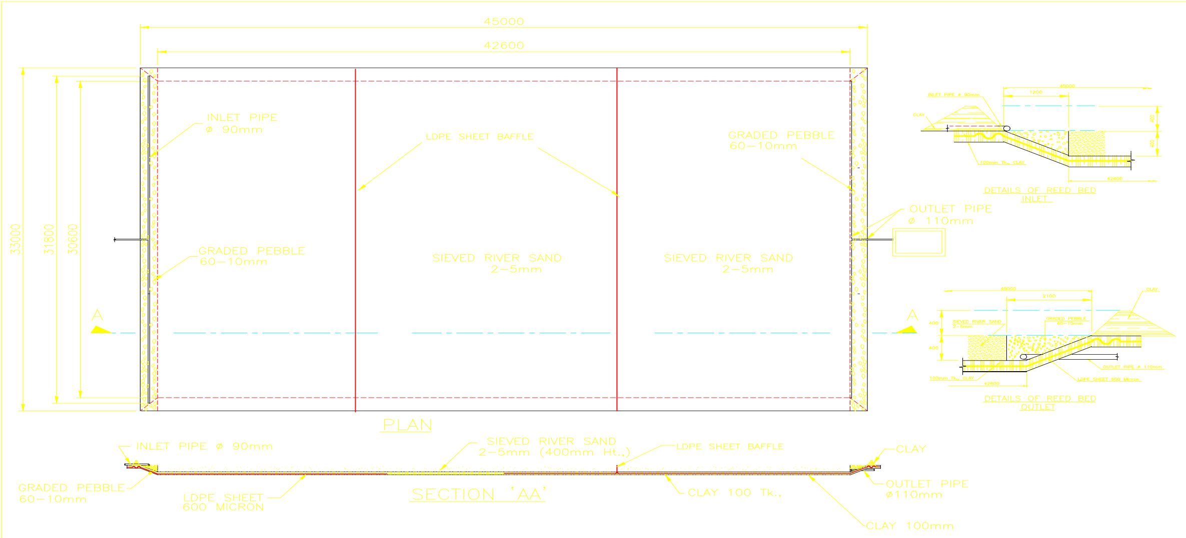
**$BOD_5$**

| Month | Mean Inflow $m^3/d$ | $BOD_5$ in Offer mg/l | $BOD_5$ in Offer kg/d | Mean Outflow $m^3/d$ | $BOD_5$ in Outflow mg/l | $BOD_5$ in Outflow kg/d | % of $BOD_5$ reduction | Specific reduction $g/m^2/d$ |
|---|---|---|---|---|---|---|---|---|
| Feb-99 | 54.30 | 354.50 | 19.25 | 49.20 | 64.30 | 3.16 | 83.57 | 25.78 |
| Mar-99 | 55.10 | 896.80 | 49.41 | 49.40 | 75.00 | 3.71 | 92.50 | 73.25 |
| Apr-99 | 48.90 | 535.10 | 26.17 | 43.90 | 152.50 | 6.69 | 74.41 | 31.20 |
| May-99 | 62.00 | 612.70 | 37.99 | 55.10 | 91.50 | 5.04 | 86.73 | 52.80 |
| Jun-99 | 59.60 | 403.30 | 24.04 | 50.90 | 124.30 | 6.33 | 73.68 | 28.38 |
| Jul-99 | 58.90 | 546.10 | 32.17 | 55.60 | 106.30 | 5.91 | 81.63 | 42.08 |
| Aug-99 | 64.50 | 823.80 | 53.14 | 59.30 | 138.90 | 8.24 | 84.50 | 71.95 |
| Sep-99 | 47.70 | 584.80 | 27.89 | 42.30 | 89.00 | 3.76 | 86.50 | 38.67 |
| Oct-99 | 48.30 | 588.30 | 28.41 | 43.60 | 85.80 | 3.74 | 86.83 | 39.54 |
| Nov-99 | 59.10 | 569.80 | 33.68 | 54.70 | 236.90 | 12.96 | 61.52 | 33.20 |
| Dec-99 | 44.10 | 840.60 | 37.07 | 38.50 | 197.10 | 7.59 | 79.53 | 47.25 |
| Jan-00 | 60.70 | 610.70 | 37.07 | 53.00 | 175.70 | 9.31 | 74.88 | 44.48 |
| Feb-00 | 56.90 | 733.70 | 41.75 | 50.60 | 200.40 | 10.14 | 75.71 | 50.65 |
| Mar-00 | 58.20 | 988.20 | 57.51 | 51.20 | 365.80 | 18.73 | 67.44 | 62.15 |
| Aug-00 | 55.70 | 695.46 | 38.74 | 53.52 | 222.29 | 11.90 | 69.29 | 43.01 |
| Sep-00 | 53.77 | 522.59 | 28.10 | 48.19 | 106.47 | 5.13 | 81.74 | 36.81 |
| Oct-00 | 58.01 | 734.59 | 42.61 | 54.31 | 137.88 | 7.49 | 82.43 | 56.29 |
| Nov-00 | 48.23 | 594.73 | 28.68 | 43.42 | 89.94 | 3.91 | 86.39 | 39.71 |
| Dec-00 | 49.83 | 591.66 | 29.48 | 45.54 | 93.93 | 4.28 | 85.49 | 40.39 |
| Jan-01 | 51.98 | 622.40 | 32.35 | 47.74 | 137.00 | 6.54 | 79.78 | 41.37 |
| Feb-01 | 61.25 | 749.42 | 45.90 | 57.76 | 139.92 | 8.08 | 82.39 | 60.61 |
| Mar-01 | 54.45 | 722.42 | 39.34 | 52.73 | 170.33 | 8.98 | 77.17 | 48.64 |
| **Mean** | **55.07** | **650.99** | **35.94** | **50.02** | **145.51** | **7.35** | **79.73** | **45.83** |

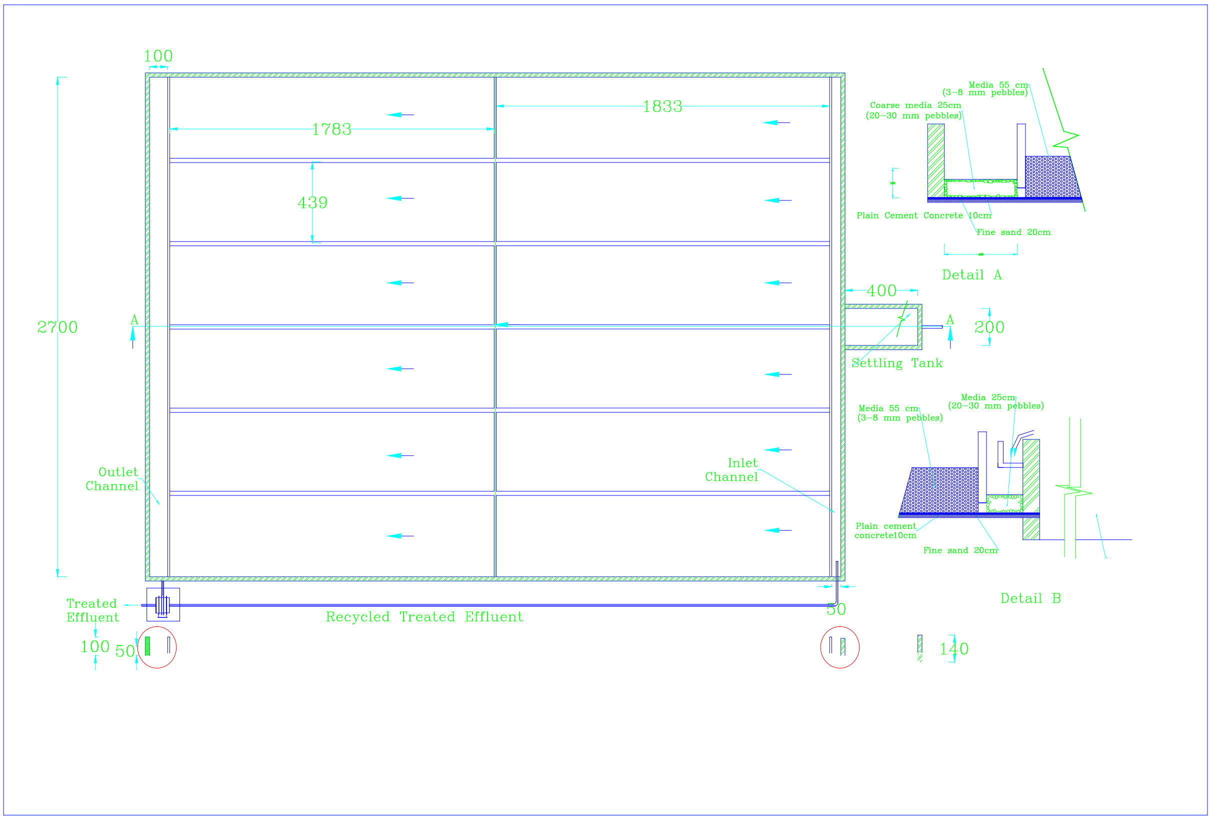
**COD**

| Month | Mean Inflow $m^3/d$ | COD in Offer mg/l | COD in Offer kg/d | Mean Outflow $m^3/d$ | COD in Outflow mg/l | COD in Outflow kg/d | % of COD reduction | Specific reduction $g/m^2/d$ |
|---|---|---|---|---|---|---|---|---|
| Feb-99 | 54.30 | 849.00 | 46.10 | 49.20 | 493.50 | 24.28 | 47.33 | 34.97 |
| Mar-99 | 55.10 | 896.80 | 49.41 | 49.40 | 567.40 | 28.03 | 43.28 | 34.27 |
| Apr-99 | 48.90 | 1671.80 | 81.75 | 43.90 | 1104.60 | 48.49 | 40.68 | 53.30 |
| May-99 | 62.00 | 1702.00 | 105.52 | 55.10 | 970.00 | 53.45 | 49.35 | 83.46 |
| Jun-99 | 59.60 | 1364.70 | 81.34 | 50.90 | 579.00 | 29.47 | 63.77 | 83.12 |
| Jul-99 | 58.90 | 1369.30 | 80.65 | 55.60 | 534.50 | 29.72 | 63.15 | 81.62 |
| Aug-99 | 64.50 | 1677.60 | 108.21 | 59.30 | 611.70 | 36.27 | 66.48 | 115.27 |
| Sep-99 | 47.70 | 1515.30 | 72.28 | 42.30 | 408.40 | 17.28 | 76.10 | 88.15 |
| Oct-99 | 48.30 | 1298.30 | 62.71 | 43.60 | 318.10 | 13.87 | 77.88 | 78.27 |
| Nov-99 | 59.10 | 1244.00 | 73.52 | 54.70 | 671.60 | 36.74 | 50.03 | 58.95 |
| Dec-99 | 44.10 | 1962.30 | 86.54 | 38.50 | 661.80 | 25.48 | 70.56 | 97.85 |
| Jan-00 | 60.70 | 1526.60 | 92.66 | 53.00 | 737.10 | 39.07 | 57.84 | 85.89 |
| Feb-00 | 56.90 | 1813.70 | 103.20 | 50.60 | 896.80 | 45.38 | 56.03 | 92.66 |
| Mar-00 | 58.20 | 2221.50 | 129.29 | 51.20 | 1324.90 | 67.83 | 47.53 | 98.49 |
| Aug-00 | 55.70 | 1975.98 | 110.06 | 53.52 | 983.62 | 52.64 | 52.17 | 92.02 |
| Sep-00 | 53.77 | 1699.80 | 91.40 | 48.19 | 710.48 | 34.24 | 62.54 | 91.60 |
| Oct-00 | 58.01 | 2030.47 | 117.79 | 54.31 | 790.50 | 42.93 | 63.55 | 119.96 |
| Nov-00 | 48.23 | 1904.73 | 91.87 | 43.42 | 775.06 | 33.65 | 63.37 | 93.29 |
| Dec-00 | 49.83 | 1973.25 | 98.33 | 45.54 | 750.57 | 34.18 | 65.24 | 102.80 |
| Jan-01 | 51.98 | 2137.14 | 111.09 | 47.74 | 767.27 | 36.63 | 67.03 | 119.33 |
| Feb-01 | 61.25 | 2124.73 | 130.14 | 57.76 | 810.17 | 46.80 | 64.04 | 133.56 |
| Mar-01 | 54.45 | 1932.00 | 105.20 | 52.73 | 1054.72 | 55.62 | 47.13 | 79.46 |
| **Mean** | **55.07** | **1676.86** | **92.23** | **50.02** | **750.99** | **37.82** | **58.87** | **87.19** |

# Annex 3
# Sketch of the reed bed system developed at Vishtec




ANNEX 3: FIG 1: SKETCH OF REED BED AT CETP, VISTHEC



**Annex 4**

# PERFORMANCE ANALYSIS OF THE REED BED SYSTEM AT VISHTEC

**$BOD_5$**

| Month | Mean Inflow $m^3$/d | $BOD_5$ in Offer mg/l | $BOD_5$ in Offer kg/d | Mean Outflow $m^3$/d | $BOD_5$ in Outflow mg/l | $BOD_5$ in Outflow kg/d | % of $BOD_5$ reduction | Specific reduction g/$m^2$ /d |
|---|---|---|---|---|---|---|---|---|
| Aug-99 | 54.00 | 799.90 | 43.19 | 46.55 | 138.90 | 6.47 | 85.03 | 58.86 |
| Sep-99 | 51.36 | 752.65 | 38.66 | 44.28 | 89.00 | 3.94 | 89.81 | 55.64 |
| Oct-99 | 37.82 | 730.50 | 27.62 | 32.60 | 85.80 | 2.80 | 89.87 | 39.79 |
| Nov-99 | 39.82 | 681.00 | 27.12 | 34.33 | 236.90 | 8.13 | 70.01 | 30.43 |
| Dec-99 | 53.68 | 684.72 | 36.76 | 46.28 | 197.10 | 9.12 | 75.18 | 44.29 |
| Jan-00 | 55.15 | 753.33 | 41.54 | 47.54 | 175.70 | 8.35 | 79.89 | 53.19 |
| Feb-00 | 40.00 | 795.40 | 31.81 | 34.48 | 200.40 | 6.91 | 78.28 | 39.91 |
| Mar-00 | 24.53 | 665.89 | 16.34 | 21.15 | 365.80 | 7.74 | 52.64 | 13.78 |
| Sep-00 | 21.10 | 318.23 | 6.71 | 22.39 | 30.57 | 0.68 | 89.81 | 9.66 |
| Oct-00 | 15.91 | 430.63 | 6.85 | 16.43 | 65.88 | 1.08 | 84.20 | 9.25 |
| Nov-00 | 39.77 | 693.73 | 27.59 | 30.64 | 64.27 | 1.97 | 92.86 | 41.06 |
| Dec-00 | 45.81 | 737.00 | 33.76 | 44.38 | 40.40 | 1.79 | 94.69 | 51.23 |
| Jan-01 | 35.00 | 584.00 | 20.44 | 35.01 | 32.00 | 1.12 | 94.52 | 30.96 |
| Feb-01 | 37.17 | 576.83 | 21.44 | 34.23 | 32.00 | 1.10 | 94.89 | 32.60 |
| Mar-01 | 41.58 | 672.46 | 27.96 | 32.05 | 66.00 | 2.12 | 92.43 | 41.42 |
| **Mean** | **39.51** | **658.42** | **27.19** | **34.82** | **121.38** | **4.22** | **84.28** | **36.80** |

**COD**

| Month | Mean Inflow $m^3$/d | COD in Offer mg/l | COD in Offer kg/d | Mean Outflow $m^3$/d | COD in Outflow mg/l | COD in Outflow kg/d | % of COD reduction | Specific reduction g/$m^2$ /d |
|---|---|---|---|---|---|---|---|---|
| Aug-99 | 54.00 | 1677.60 | 90.59 | 46.55 | 611.70 | 28.47 | 68.57 | 99.54 |
| Sep-99 | 51.36 | 1515.30 | 77.83 | 44.28 | 408.40 | 18.08 | 76.77 | 95.75 |
| Oct-99 | 37.82 | 1298.30 | 49.10 | 32.60 | 318.10 | 10.37 | 78.88 | 62.06 |
| Nov-99 | 39.82 | 1244.00 | 49.54 | 34.33 | 671.60 | 23.06 | 53.46 | 42.44 |
| Dec-99 | 53.68 | 1962.30 | 105.35 | 46.28 | 661.80 | 30.63 | 70.93 | 119.74 |
| Jan-00 | 55.15 | 1526.60 | 84.19 | 47.54 | 737.10 | 35.04 | 58.38 | 78.76 |
| Feb-00 | 40.00 | 1813.70 | 72.54 | 34.48 | 896.80 | 30.92 | 57.37 | 66.70 |
| Mar-00 | 24.53 | 2221.50 | 54.50 | 21.15 | 1324.90 | 28.02 | 48.59 | 42.44 |
| Sep-00 | 21.10 | 1275.48 | 26.91 | 22.39 | 295.14 | 6.61 | 75.45 | 32.54 |
| Oct-00 | 15.91 | 1277.75 | 20.33 | 16.43 | 305.50 | 5.02 | 75.31 | 24.53 |
| Nov-00 | 39.77 | 1253.27 | 49.84 | 30.64 | 376.87 | 11.55 | 76.83 | 61.37 |
| Dec-00 | 45.81 | 1334.69 | 61.14 | 44.38 | 279.70 | 12.41 | 79.70 | 78.09 |
| Jan-01 | 35.00 | 1223.29 | 42.82 | 35.01 | 292.86 | 10.25 | 76.05 | 52.18 |
| Feb-01 | 37.17 | 1148.50 | 42.69 | 34.23 | 269.17 | 9.21 | 78.42 | 53.65 |
| Mar-01 | 41.58 | 1222.31 | 50.82 | 32.05 | 374.30 | 12.00 | 76.40 | 62.22 |
| **Mean** | **39.51** | **1466.31** | **58.55** | **34.82** | **521.60** | **18.11** | **70.07** | **64.80** |

Note: Data during March-September, 2000 is not presented as the bed was under rectification work during this period. In the months of March, September and October, lower organic load was admitted to the bed, as the feed was a mixture of primary and secondary treated effluent.

**Annex 5**

## Conceptual design of a simplified ETP for treatment of tannery effluent for isolated tanneries incorporating reed bed for secondary (biological) treatment

### 1. Introduction

It may be possible to incorporate the reed bed system as a secondary treatment system for isolated tanneries where sufficient land is available and required technical skills may not be available for operation and maintenance of a conventional biological treatment system such as activated sludge treatment.

The normal physico-chemical treatment (perhaps even more stringent chemically aided sedimentation) may be required in this case too. Since there could be a possibility that finer organic levels (say 30 mg/l) may not be achieved at the end of the reed bed treatment, a simple post treatment, say aerobic stabilisation pond may be required depending on the type of effluent (particularly the bio-degradability of the organics) and the degree of treated effluent standards required.

To protect the reed bed from any occasional overflow of solids from the primary settling tank, it may be required to provide a settling compartment at the inlet of the reed bed. Since in some cases it has been noticed that re-circulation of treated effluent from reed bed to the inlet is giving a better result, it may be useful to make a provision for recycling also.

A conceptual design for an ETP including reed bed as one of its parts for an isolated tannery generating about 100 $m^3$/day effluent is given below. However it should be noted that the assumptions are based on the data collected till now and further studies and trials are needed to establish the feasibility of the proposed system with respect to specific locations.

### 2. Conceptual treatment system suggested

It is assumed that the effluent is from a chrome tannery processing raw to finished leather with around 2500 mg/l COD and 1000 mg/l BOD.

The effluent from the tannery shall be passed through two screens, one with 20 mm bar spacing and the second with finer bar spacing of 10 mm, and the coarse solids and grit are allowed to settle in a pre-settling unit having a dimension of 1 m x 3 m x 1 m (liquid depth). Then the effluent is admitted into the equalisation-cum-collection tank of dimension 10 m x 5 m x 2 m (liquid depth) provided with two numbers of floating aerators of 1.5 kW. The equalised effluent is then pumped using a non clog, open impeller, self priming centrifugal pump at the rate of 5 $m^3$/h to a coagulation-cum-flocculation tank of dimensions 1 m x 1 m x 0.8 m (liquid depth) provided with a mixer. Chemical slurries @5-10% concentrations (alum at 300 mg/l -dry weight basis and lime for neutralisation of the mixture) are suggested. Addition of 1 mg/l of anionic polyelectrolyte solution (prepared at 0.05%) may be considered depending on the technical skills of the operating staff and availability of the chemical. The chemically coagulated effluent shall then enter a settling tank of dimensions 4 m diameter and 2 m side water depth with a 1:10 slope towards the central sludge collection chamber. The construction of this tank shall be similar to a normal clarifier, but a scrapper mechanism could be avoided if the operational attention for proper sludge evacuation is ensured (of course, in such case the hopper bottom should be steeper). All the above tanks would be constructed in RCC where as for construction of screen channel and grit chamber, brick masonry too could be considered.

The overflow of the settling tank would be taken to a settling chamber. It is suggested to construct this pond in brick masonry. The tank size suggested is 6 m (length) x 4 m (width) x 1.4 (total depth). It is suggested to de-sludge this tank, every month.

The overflow from this tank shall enter the inlet channel of the reed bed. Depending on the local soil conditions and other considerations, the reed bed can have either a compacted clay layer + LDPE/HDPE sheet liner (>600 micron) or a standard PCC bottom. Sidewalls and partition walls in brick masonry for a depth of 1.0 m. Media (graded sand 3-8 mm) for a depth of 0.55 m. The overall dimensions of the reed bed are 48 m x 36 m x 0.55 m (media depth).

The improved distribution arrangement is expected to be realised by inlet and outlet channels and internal channels formed by a series of baffle walls made of brick masonry. The inlet and outlet channels will be filled with pebbles of size 20 mm-30mm upto a height of 0.25 m.

The inlet channel will have a dimension of 0.5 m (length) x 36.0 m (width) x 1.0 m. (total depth). Outlet channel will have 1 m (length) x 36.0 m (width) x 1.0 m (total depth). The inlet to this channel will be the overflow from settling tank, distributed equally to all the compartments.

The treated effluent shall be pumped out from the outlet channel, which also serves as the treated effluent collection tank. One line from the pumped outlet shall be laid back to the inlet channel to re-circulate the treated effluent as and when required.

The outlet of the reed bed shall be taken to a polishing pond where further reduction of BOD/ COD is expected. The overflow from the polishing pond shall be discharged as treated effluent.

The sludge from the settling tank shall be taken to the sludge drying beds for dewatering.

## 3. Comparison of the system suggested with conventional treatment system

### 3.1 General

A brief comparison of the conceptual arrangement suggested above with a conventional activated sludge based system is given below:

| Parameter | Reed based system | Activated sludge system |
|---|---|---|
| Performance security | To be proven based on further trials and installations | Well proven |
| Requirement of physico-chemical treatment | Required | Required |
| Land requirement | High (Approximately 3200 $m^2$) | Less (Approximately 800 $m^2$) |
| Maintenance | Moderate | High |
| Monitoring | Moderate | High |
| Stabilisation time | > 6 months | 3 months |

| | | |
|---|---|---|
| Other environmental benefits (land utilisation/ greening of area etc.) | Positive | -- |
| Consistence in performance | Unknown | Consistent |
| Controllability | Easy-medium | Easy-medium |
| Requirement of skilled personnel | Medium-high | High |

Basis of comparison: Effluent flow: 100 $m^3$/d, characteristics of effluent: from raw to finished tanning process.

### 3.2 Installation and operational cost

**Installation cost**

| Unit | Option with activated sludge | | Option with reed bed | |
|---|---|---|---|---|
| | Value | Cost (INR) | Value | Cost (INR) |
| Screens, grit chamber etc. | LS | 18,000 | LS | 18,000 |
| Equalisation tank with aerators | 100 $m^3$ volume, 5 HP floating aerator | 280,000 | 100 $m^3$ volume, 5 HP floating aerator | 280,000 |
| Flash mixer, flocculator chemical dosing, primary clarifier | HRTs: Flash mixer 5 min, flocculator 20 min & clarifier 3 hrs | 290,000 | HRTs: Flash mixer 5 min, flocculator 20 min & clarifier 3 hrs | 290,000 |
| Aeration tank-1 | 130 $m^3$ volume, 2 x 5 HP aerator | 540,000 | Reed bed: 3 beds of total area 2400 $m^2$ | 680,000 |
| Aeration tank-2 | 80 $m^3$ volume, 1 x 7.5 HP fixed aerator | 330,000 | ---- | 0 |
| Secondary clarifier | 3.5 hours HRT | 190,000 | Polishing pond: 150 m2 x 1m | 120,000 |
| Sludge drying beds | 400 $m^2$ area | 320,000 | 350 $m^2$ area | 280,000 |
| Miscellaneous | All other including electrical & piping | 550,000 | All other including electrical & piping | 550,000 |
| Land cost | Approx. 800 $m^2$ | 80,000 | Approx. 3200 $m^2$ | 320,000 |
| Total | | 2,598,000 (US $ 56500) | | 2,538,000 (US $ 55000) |

**Operational cost (per day)**

| Item | Option with activated sludge | | Option with reed bed | |
|---|---|---|---|---|
| | Value | Cost (INR) | Value | Cost (INR) |
| Chemicals | Alum, Lime 300 ppm, PE 1 ppm | 175 | Alum, Lime 300 ppm, PE 1 ppm | 175 |
| Total power | Approximately 400 kWh/d | 1600 | Approximately 140 kWh/d | 560 |
| Manpower | One plant manager, | 1100 | One plant | 1000 |

| | | | | |
|---|---|---|---|---|
| | one chemist, four operators, three technicians, two supporting staff | | manager, one chemist, four operators, one technician, two supporting staff | |
| Lab analysis | LS | 100 | LS | 100 |
| Maintenance* | LS | 980 | LS | 620 |
| Sludge dewatering/ disposal | LS | 120 | LS | 110 |
| Depreciation | 15% on electro-mechanical and 5% on civil | 655 | 15% on electro-mechanical and 5% on civil | 525 |
| Total | | 4730 | | 3090 |
| Total annual cost | Assuming 300 d/y | 1419000 (US $ 31000) | | 927300 (US $ 20000) |
| Treatment cost/$m^3$ | | INR 47.3 (US $1.02) | | INR 30.9 (US $ 0.67) |

**** Projections based on actual figures.***

As it can be seen, the investment cost of the two options are US $ 57478 and US $ 56150 respectively (assuming a RoE 1 US $ = 45.2) and the annual operation cost is US $ 31393 and US $ 20508 (34% less) respectively. In short, the reed bed option can give a saving of US $ 1328 in investment and US $ 10885 in annual operation cost. This is however, assuming that the reed bed option will work as efficiently as the activated sludge system, which, in our opinion, is yet to be proved.

One major advantage of the reed bed option is the relatively lower operational control which makes this virtually the only alternative in many countries in the region, where technical capability to manage an activated sludge system is scarce. The other positive environmental aspects, (absence of aerosols, improved aesthetics etc.) will also need to be considered.