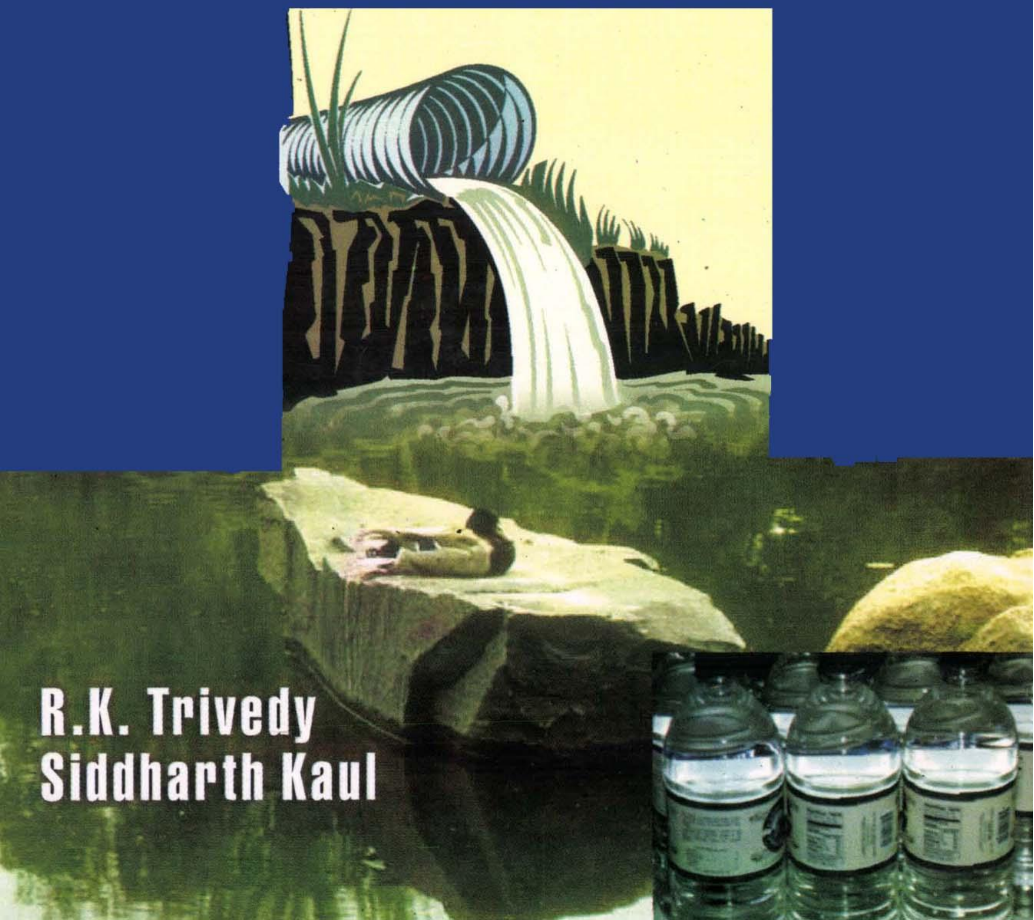
LOW COST WASTEWATER TREATMENT TECHNOLOGIES



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The Combined Treatment of Domestic Septage and Industrial Wastes by Oxidation Ditches

Introduction

Traditionally household sanitation in most developing countries was carried out with the use of dry pit latrines and later with septic tanks followed by absorption pits. The increased demand of potable water as a consequence of the abrupt rise of the standard of living of both rural and urban populations has rendered, in many cases, the existing domestic sewage disposal methods are totally inadequate. The increased volume of sewage coupled in many cases with unfavourable ground conditions where soil permeability is limited, leads very often to overflowing absorption pits with ill-consequences to both the health and the welfare of the population.

Similar problems exist with the disposal of industrial wastes. In many countries, mainly developing, industrial activity is in a small scale, most of the time being family businesses. These small businesses although in general produce small quantities of wastewater, nevertheless the aggregated pollution they create could be substantial. The small size of these businesses, however, coupled with the small quantities of the wastewater they produce renders their treatment by the industries themselves uneconomic and practically not feasible.

Problems such as the above have existed in Cyprus for quite a while. The standard of living of the population is of the highest in Europe. This rapid economic development has occurred over the last 20 years or so and led to an increased water consumption by households, while at the same time a number of sectors of the industry, especially food processing, has shown considerable development. The increased water consumption as a result of the rise of the standard of living of the population, which despite the drought conditions which more than often occur, is today 120 l/head/day and 90 l/head/day for the urban and rural population respectively. Approximately 75 per cent of the above waste is discharged as wastewater.

Over the last few years the major tourist towns of the island which have been facing most of the problems have proceeded with the construction of sewerage networks and sewage treatment plants. However, large parts of the capital Nicosia as well as many small villages are still without central sewerage network and the houses that are served by septic tanks and absorption pits face the sometimes weekly or even daily (for the multi-storeyed buildings) inconvenience of emptying the absorption pits using private tankers which in turn have to dispose this septage/septic water in an acceptable manner. Similar problems occur with industry. Although the large and financially strong companies have installed their own wastewater treatment plants, small industries do not have the means to do so and, therefore, they too have to be served by private tankers which collect the wastewater from their septic tanks and absorption pits.

In order to solve the problem of the disposal of all these tankered wastes, the Government of Cyprus has decided in 1994 to proceed with the construction of a wastewater treatment plant at a greenfield site, to treat both domestic septage and industrial wastes. The plant, called the Vathia Gonia Central Wastewater Treatment Plant (CWWTP), although expensive as an independent unit, is the most economic short to medium term solution. Over and over again it is proven that at least under Cyprus conditions the cost of a treatment plant is approximately 25 per cent of the total cost for the implementation of a complete sewerage network and sewage treatment project. Therefore, the construction of a plant to treat these tankered wastes was the quickest and most acceptable solution, under the prevailing conditions.

Treatment Plant Description

Design Parameters

The treatment plant has been designed to treat the quantities and wastes as they appear in table 1. All wastes are tankered to the site by private tanker owners who are called by their customers

Table 1 - Average Design Flows and Loads (Calculated on 7 Days Week Basis)

	Flow m^3/d		BOD Kg/d		COD Kg/d		SS Kg/d		NH_3 Kg/d	
Year	1994	2004	1994	2004	1994	2004	1994	2004	1994	2004
Waste Type										
Metal Industries	36	48	10	13	25	33	9	12	0.3	0.5
Fats/Oils/Grease	26	35	70	93	126	168	48	64	0.8	1.2
Strong Organic	56	75	310	413	568	761	192	256	1.7	2.2
Weak Organic	161	215	153	204	325	433	43	57	4.8	6.3
Dairy Wastes	108	144	1,073	1,430	1,785	2,380	748	997	3.2	4.2
Domestic septage	1,263	1,683	904	1,207	2,181	2,905	2,100	2,804	135	18.0
Total/Average	**1,650**	**2,200**	**2,520**	**3,360**	**5,010**	**6,680**	**3,140**	**4,190**	**146**	**19.4**

Imported Sludge

Surplus Activated Sludge	48	65	Not Known	Not Known	Not Known	Not Known
DAF Flotate (Dying–4% Solids)	30	40	Not Known	Not Known	Not Known	Not Known
Juice Pulp	2	3	Not Known	Not Known	Not Known	Not Known
Total	80	108	Not Known	Not Known	Not Known	Not Known

(households or industries), to empty their septic tanks and absorption pits. The most difficult design parameter was to identify and characterise these wastes, both industrial and domestic. Domestic septage show great variability upon the area where they are collected from. If collected from absorption pits of multi-storeyed buildings which are emptied very often, sometimes daily, they tend to have much lower BOD_5 and SS concentration than when collected from residences whose absorption pit and septic tank did not require emptying for substantial length of time.

Similar problems occur with industrial wastes. Both the quantities and characteristics produced from these small industries are erratic and very difficult to control. Hence, although systematic sampling was carried out in order to characterise these wastes field data collected after the plant was set into operation showed marked differences.

Cyprus, being a country which very often experiences droughts, has to take all possible measures in order to save and utilise all available water resources. The use of recycled water in agriculture as a substitute of potable quality water, has been in the priority list of successive governments and is considered to be one of the main contributors to water resources. Hence in this case, as in all other sewerage systems on the island, recycled water distribution projects go in parallel with the construction of sewage treatment plants.

Discharge Control and Regulation

One of the main problems encountered at such a plant is regulating and controlling the tankered wastes. Depending on the method of billing for the disposal of the wastes the tanker drivers may or may not have a strong incentive to declare different waste and discharge it at the wrong position, causing operational problems to the works. A second problem that occurs is the fact that large tankers, although not allowed to mix wastes from different sources (industrial with domestic or industrial with industrial of a different category) they will try to do so since they are not prepared to travel and discharge to the treatment works half full.

In order to minimise these problems, a highly sophisticated electronic procedure has been adopted. All registered tankers which are allowed to discharge wastes at the treatment plant, have a transponder installed on their chassis. Also so as to prevent tanker drivers declaring the wrong waste, two types of dockets are issued; domestic and industrial. Domestic dockets are held by the tanker drivers while industrial dockets are held by the industries.

Upon arrival at the plant the tanker is automatically recognised and registered at a local computer. Following its recognition, the tanker driver delivers through his window to an operator in the reception room the docket indicating the source of the waste. Since dockets are allocated to each customer (tanker driver for the domestic, industry for the industrial wastes), the operator by entering the docket number into the computer automatically confirms the source of the waste. This data is held in the computer for monitoring the flows and sources of wastes as well as for billing purposes.

After the docket is confirmed as being valid, the computer will display to the operator the discharge bay where the waste should be discharged. There are 23 discharge bays as follows:-

One for Metal Wastes (MW).
One for Strong Organic Wastes (SOW).
One for Weak Organic Wastes (WOW).
One for Fats, Oils and Grease (FOG) wastes.
One for imported sludge.
Two for dairy wastes.
Sixteen for domestic septage.

The tanker driver will then drive to the appropriate bay where the truck will again be recognised as being to the right position. He then connects the hose of the tanker to a pipe and discharges. However, if he has parked for whatever reason at the wrong position or if there is equipment malfunction downstream then a red light by the bay will indicate so and the electric gate valve that permits the discharge will not open. The operators of the plant will be aware of what happened through the computer screen in the reception room and act accordingly.

Treatment Processes

A simplified schematic of the treatment plant appears in figure 1.

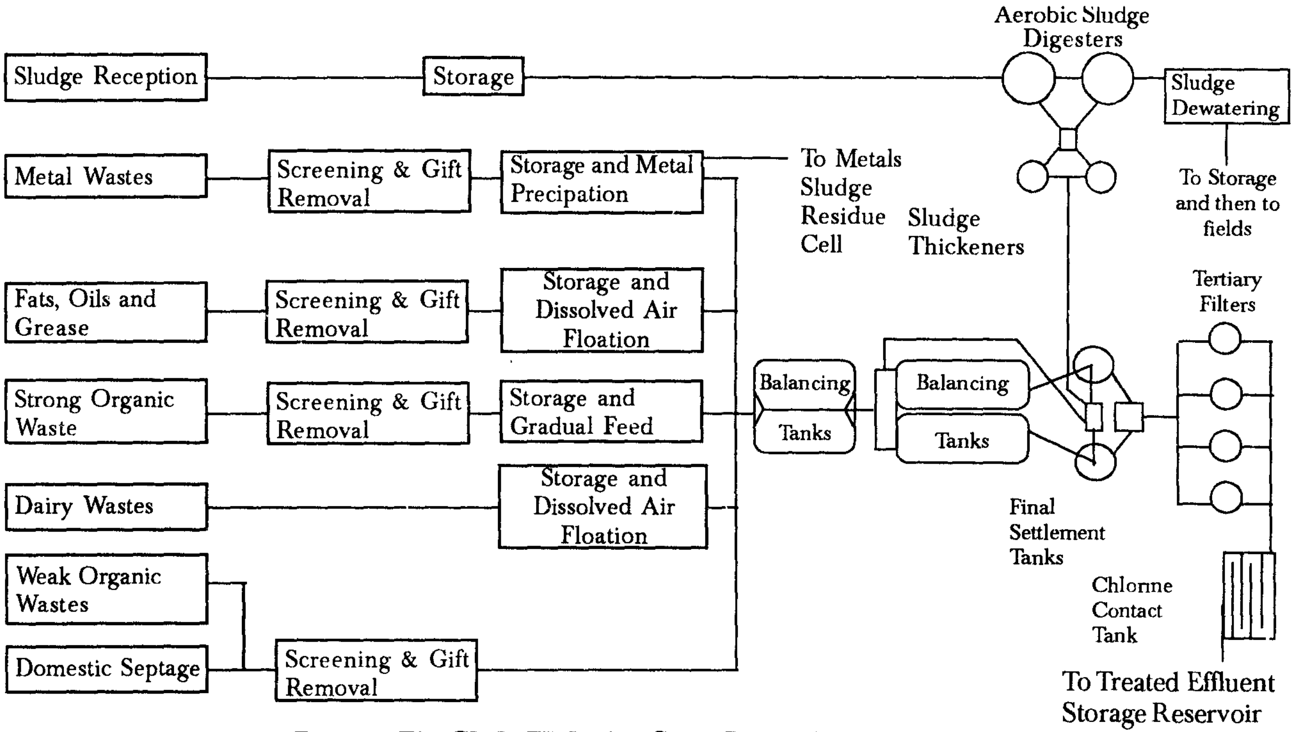

Figure 1: The CWWTP, Vathia Gonia Process Block Diagram

Pre-treatment of wastes

Metal Wastes

The sources of metal bearing wastes are aluminium anodising industries, nickel plating, galvanising as well as chromium streams from tanneries. Obviously these wastes contain a varying content of metals depending not only on the source but also on the particular batch. Therefore, the treatment of these wastes since they are delivered in a batch mode can only take place in the same manner.

Metal wastes after being discharged by the tanker are first screened trough a 6 mm rotating drum screen and the grit is removed in an aerated grit removal unit. The screening/grit removal takes place in a pre-fabricated stainless steel unit.

After screening and grit removal, the waste is directed into one of three 30 m^3 storage tanks. The tanks are filled in series with automatic change-over when one gets full. When a tank gets full then a sample is collected and analysed at the plants' laboratory, for its contents in metals. After the metals have been identified then tests are carried out with various chemicals which are available for the treatment, in order to determine the necessary quantities required in order to precipitate them.

The waste is then pumped into one of two metal treatment tanks equipped with submersible mixers, where the chemicals, as determined in the laboratory, are dosed in the appropriate quantities. The chemicals available for dosing are caustic soda, sulphuric acid, cationic and anionic polyelectrolytes.

After dosing the chemicals, the waste is transferred in one of two 30 m^3 settlement tanks where the metals will precipitate. The settled sludge is then pumped into one of two sludge storage tanks. In these tanks conditioners are added in the form of polyelectrolytes and the sludge is subsequently pumped into two (one duty, one stand-by) plate filter presses. The dewatered sludge is transferred via a belt conveyor into a lagoon lined with one millimeter HDPE membrane. The capacity of this lagoon is estimated to last for approximately 20 years. A ramp at the side of the lagoon permits access to a small tractor to decent into it and spread the sludge in layers.

The supernatant of the treatment tanks and the press liquor of the presses flows by gravity into the treatment tank balancing tank.

Fats, Oils and Grease Wastes (FOG)

The category FOG wastes comprises wastes from mainly the food industry as well as other manufacturing industries such as water-based paints. These wastes have a high content of floating matter in terms of fats, oils or grease.

The treatment line of these wastes comprises screening and grit removal in a package unit, followed by three 30 m^3 each holding tanks which are filled in series. The wastewater after being sampled is tested to determine the required dosage and type of chemicals required in order to coagulate and flocculate the fats, oils and greases.

The storage tanks are followed by a Dissolved Air Flotation (DAF) unit. The determined chemicals are added in the wastewater and after coagulation/flocculation has occurred the fats/oils and greases are floated in the DAF unit.

The floated materials are scraped from the surface by a mechanical scraper into a pump sump where the floated from the dairy DAF unit are collected. From this chamber the floated materials can either be pumped into the aerobic digesters or into two scum residue cells. The reason for these alternative methods of disposal of the floatable materials, is in case these materials prove to have detrimental effect on the operation of the digesters either due to their physical characteristics or chemical characteristics an alternative route of disposal will be available.

The liquor also flows into a pump sump where it is mixed with the liquor from the dairy DAF unit and is then pumped into the treatment plant balancing tank. However, alternative route is available in case these treated liquor could cause problems to the operation of the treatment plant. It can either be diverted into the emergency holding tanks or the emergency storage lagoon.

Dairy Wastes

Dairy wastes to be delivered to the works should not include whey which must be segregated at the factories. Although a number of companies have made the necessary modifications within the factories to segregate the whey from the washings this has not been easy and it causes significant problems to small businesses.

Dairy wastes are discharged in the normal way and is firstly stored in a mechanically mixed 200 m^3 storage tank. From this tank it is pumped in a controlled manner into a Dissolved Air Flotation unit where the fats are removed.

The floated material flows into the sump as described above while the liquor in the pump chamber where the liquor from the FOG DAF is discharged. From this pump chamber all liquors are pumped to the works balancing tank.

Strong Organic Wastes

Strong Organic Wastes (SOW) are firstly screened and treated for grit removal in a package unit as all other streams. After screening and grit removal the wastewater flows into one of six mechanically mixed holding tanks. Three are 30 m^3 each while the other three 15 m^3 each. The wastewater stored in these tanks is pH adjusted and samples taken in order to determine its strength (COD). According to the analysis carried out, the contents of the tanks are gradually fed to the balancing tanks via variable speed positive displacement pumps so that any shock to the system is avoided.

Weak Organic Wastes

Weak Organic Wastes (WOW) are those industrial wastes whose characteristics are very similar to those of the domestic septage. These wastes are, therefore, treated the same way as the domestic septage.

Imported Sludge

Sludge treatment in any plant is a very expensive operation. Therefore, many small domestic sewage works as well as industrial wastewater treatment plants do not have their own sludge treatment facilities.

The Vathia Gonia CWWTP offers this service to all these small works by treating their liquid sludge. The sludge is delivered to the works and is first stored in a 30 m^3 storage tank. From there the sludge is pumped via macerating pumps into the aerobic digesters for further stabilisation and eventually dewatering.

Domestic Septage

Domestic septage which is the bulk of the wastewater delivered to the treatment plant is discharged to one of the 16 discharge bays allocated to this waste. The wastewater then flows through a screen/grit removal unit. The screenings and grit are discharged via screw conveyors into skips while the wastewater flows into the balancing tank.

Emergency Treatment Tanks

In a treatment plant of this nature where all wastes are tankered there is always the possibility that unknown wastes or wastes of a dubious source will be delivered. In order to cover this eventuality the plant has been provided with six emergency holding tanks 30 m^3 each followed by two 15 m^3 emergency batch settlement tanks and two 15 m^3 treatment tanks.

All wastes that are considered as being suspicious in nature instead of being processed through one of the existing pre-treatment lines are diverted in any one of the six available holding tanks. After being sampled the waste is pumped either into the batch settlement tanks or the batch treatment tanks where pH is adjusted.

Following the treatment tanks, the wastewater can be pumped in a controlled manner in the balancing tank. Should treatment in these tanks, after the analysis has been carried out, is considered inadequate for the waste to be discharged into the balancing tank, the waste may be removed by tanker and discharged into the pre-treatment line that is most appropriate.

Secondary Treatment

Balancing Tanks

All pre-treated wastes are collected in two balancing tanks (total capacity 4800 m^3) whose purpose is to equalise the flow and load which is received during the 8-hour, 5 days a week period, that the plant receives waste. Further to the pre-treated wastes the balancing tank also receives return flows from sand filters washwater, press liquor from the sludge centrifuges, thickener supernatant, administration building sewage, and drainage from the aeration tanks and final settlement tanks.

The flow into the aeration tanks is regulated by three variable speed centrifugal pumps.

Aeration Tanks

Prior to entering the aeration tanks the waste first enters an anoxic tank which is mixed by three submersible mixers. In the 660 m^3 anoxic tank the incoming waste is mixed with the return sludge so as to achieve adsorption of the organic matter on the sludge flocs and reduce the possibility of bulking.

The biological treatment of the wastewater takes place into two oxidation ditches 5700 m^3 each. The ditches are aerated by six (three in each tank) one meter diameter, nine meters long rotors each absorbing 45 kW. The oxygenation capacity of these rotors is 7 kg O2/hour/meter length of rotor; i.e. each rotor delivers at optimum immersion 56 kg O2/hour. Therefore, the oxygenation rate per aeration tank at optimum immersion is 168 kg O2/hr or 4,032 kg O2/day.

The immersion of the rotors and hence their oxygenation capacity can be adjusted via the overflow weir.

One rotor in each aeration tank is always working while the other two get in and out of operation according to the dissolved oxygen in the tank which is measured with permanently installed dissolved oxygen meters.

The aeration tanks have been designed to operate at an organic loading rate (FM ratio) of 0,085 kg BOD^5/kg MLSS, and volumetric loading rate of 0,3 kg BOD^5/m^3. Due to the high BOD^5 concentration of the incoming wastewater the hydraulic retention time is approximately 5 days in contrast to the common design of oxidation ditches where the retention time is normally 24-36 hours.

Final Settlement Tanks

The aeration tanks are followed by two circular final settlement tanks which have been designed to operate at a loading rate of 1.6 m^3/m^2/hr.

The sludge is scraped by a half-bridge scraper and is collected in a hopper at the bottom of the tanks from where it is removed via a pipe over a adjustable height bellmouth valve. The sludge is discharged into the Return Activated Sludge/

Surplus Activated Sludge (RAS/SAS) chamber. From the RAS/SAS chamber is pumped by three (two duty, one stand-by pumps) to the anoxic tank at a rate of 1,5 times the average inflow, while the remaining sludge which is the surplus is pumped to the sludge thickeners.

The supernatant liquor from the final settlement tanks overflows over v-notch weirs and into the effluent sump.

Tertiary Treatment

The secondary effluent which overflows into the effluent sump is pumped into four continuously operated/backwashed sand filters. An overflow in this chamber by-passes the sand filters and the water flows directly into the chlorination tank should there is a malfunction and the filters cannot be put into operation.

The sand filters are backwashed using compressed air and this water overflows to the works washout pumping station and from there to the balancing tank.

The tertiary treated water overflows into a chlorination tank of 1 hour hydraulic retention time where it is chlorinated with gas chlorine in order to maintain a residual chlorine of 2mg/l.

After chlorination the water overflows into a storage lagoon where it is stored to be used for irrigation.

Sludge Treatment

Sludge Thickeners

The sludge treatment comprises thickening, aerobic digestion and dewatering with centrifuges. As mentioned above the treatment plant also receives sludge from other smaller works which do not have their own sludge treatment facilities.

The surplus sludge is pumped from the RAS/SAS pumping station to two picket fence thickeners of diameter 0.9 m each. Both thickeners in addition to the overflow weir also have internal decanter so that if desired they can be operated in a batch mode.

The supernatant liquor overflows into a chamber and from there it is directed to the works washout pumping station and eventually to the balancing tank. The thickened sludge is pumped via two positive displacement pumps to the aerobic digesters.

Aerobic Digestion

Stabilisation of the sludge occurs in two aerobic digesters in series. Each tank is 2,350 m^3 and is made of glass enamel coated steel. Aeration accomplished by 21 helixor type diffusers and three routes type blowers (two duty, one stand-by) each delivering 350 m^3N/hr.

The design hydraulic retention time in the digesters is 20 days in order to comply with the EU directive 86/278/EEC.

The second of the two digesters in addition to the overflow weir, also has internal decant facilities so that sludge may be further thickened prior to being processed to the centrifuges for dewatering. The supernatant liquor of the digesters like all other liquors is pumped to the works washwater pumping station and from there to the balancing tanks.

Sludge Dewatering

The digested sludge is dewatered by two (one duty, one stand-by) centrifuges each having capacity to treat 750 kg solids per hour. Polyelectolytes are added in the sludge for conditioning prior to dewatering and in order to save potable water these are made-up with treated effluent.

The dewatered sludge is conveyed via a screw conveyor into a trailer and tipped onto a 7000 m^2 concrete platform where it is stored for at least three months before is taken to the fields to be used as a soil conditioner.

Odour Control

Wastewater and especially septage as in this case, cause serious odour nuisance due to its hydrogen sulphite content. In order to minimise odour problems a number of steps have been taken in order to contain the areas where odour is emitted and treat the odorous air.

All screen/grit removal units, the pre-treatment building and the balancing tanks are covered and vented by two extractor fans through a biofilter. The air changes attained in these units vary between one and ten per hour. The total air that is treated per hour is 16,157 m^3/hr while the diameter of the biofilter is 11 m.

The screen/grit removal units are stainless steel and are, therefore, enclosed with a stainless steel cover. The roof of the balancing tanks are GRP panels, while all ducting is stainless steel in order to avoid corrosion problems.

The other area of the plant where malodours may be emitted is the sludge treatment area. Therefore, the thickeners and sludge digesters are covered with GRP covers and vented also through a biofilter. The sludge dewatering building is also vented through the same ducting system through the biofilter.

The fans that extract the air from these areas deliver 7,122 m^3/hr and the biofilter has a diameter of 10 m.

Operational Performance

The plant has been designed to treat overall 3,600 kg BOD^5/ day or a p.e. of 60.000 (at a p.e. BOD^5 of 60g/head/day) and a total maximum flow of 2,200 m^3/day. For a 60.000 p.e. the flow at 2,50l/head/day should have been 15,000 m^3/day. The low flow in relation to the high BOD^5 load results to a BOD^5 concentration significantly higher than that of ordinary domestic sewage and naturally this has reflected on the overall design of the plant.

All hydraulic design has been based on the 2,200 m^3/day while the biochemical processes have been based on the 60.000 p.e. This difference is most apparent on the design of the oxidation ditches which at 100 per cent design flow and load the hydraulic retention time is approximately 5 days in contrast to oxidation ditches treating sewered domestic sewage where the HRT is 24-36 hours.

The most difficult operational problems encountered are:

(a) The significant daily variations of flows and characteristics of the industrial wastes :

The production processes within industries, especially food industries which are the main sources of industrial wastewater to the treatment plant, are subject to both daily and seasonal variations. These industries all small and more often than not produce different products at different days of the week or season which as a result leads to different characteristics of the wastewater. Close control and monitoring of all discharges is, therefore, required, which in turn leads to substantial effort on behalf of the operators to sample and carry out all necessary analysis.

(b) The tendency of both tanker drivers and industries to misuse the system :

According to the procedures no tanker is allowed to mix domestic septage with industrial wastes. The reasons for this are obvious since each type of waste is treated in a different line. However, in many cases a single tanker would not get completely filled from a single source (domestic or industrial) and since he shall not make the trip to the treatment plant half empty he will try to complete his load. This could lead to mixing of domestic and industrial wastes which could be delivered to the plant and declared as completely domestic or as completely industrial. Although the docket system that has been implemented and has certainly reduced to a large extend the mixing of different wastes there is no doubt that it does happen. Fortunately, however, until know no ill effects have been shown on the final effluent quality mainly due to the small proportion of these wastes compared with the domestic septage which is the bulk.

The plant overall performs to the required standard constantly achieving a final effluent of less than 10/10 standard while the faecal Coliforms are almost always zero.

Plant Data

Although there is substantial amount of data in the literature on the characteristics and treatment of septage this plant is probably the first of its type build world-wide that treats domestic septage which is a combination of septic tank contents and absorption pits. Therefore, an extensive sampling has taken place prior to preparing the specifications for the implementation of the contract by taking samples from a number of tankers. Based on those results the expected domestic waste characteristics as compared to the field data collected that now the plant is in operation appear on table 2.

Table 2

Comparison of Wastewater during Design Stage and Operation Period

Waste Type	BOD (mg/l)		COD (mg/l)		SS (mg/l)		NH3-N (mg/l)	
	Design	Field Data	Design	Field Data	Design	Field Data	Design	Field Data
Domestic septage	716	978	1727	2936	1663	1660	107	165
Dairy Wastes	9935	5560	16528	17282	6926	2095	30	61
Weak Organic	950	1422	2019	7293	267	1970	30	–
Strong Organic	5536	2680	10143	17481	3429	2717	30	7
Fats/Oils/Grease	2692	3759	4846	14091	1846	4777	31	–
Metal Industries	278	–	694	13733	250	4400	8	–
Total/Average	1527	1202	3036	3794	1903	1654	88	156

Dairy Waste Pre-treatment

As indicated before dairy wastes are pre-treated by a Dissolved Air Flotation unit for the removal of fats and other suspended matter that could cause operational problems to the plant. The DAF operates without the addition of chemicals and achieves a COD reduction of approximately 30 per cent and suspended solids reduction of appoximately 39 per cent.

Fats, Oils and Grease pre-treatment

The pre-treatment of the FOG wastes is again by a DAF unit but in this case chemicals are added in order to assist coagulation and flocculation. The COD and suspended solids reduction in this case is 16.8 per cent and 35 per cent respectively.

Secondary Treatment

Following the pre-treatment all streams enter the two balancing tanks. In addition to the pre-treated wastes the balancing tank receives all return flows of the plant, such as thickener supernatant, sludge press liquor, tertiary filters backwash etc. These return flows amount to about 800 m^3/day compared to the 1,000 m^3/day that the plant receives at present. Naturally the balance tank wastewater characteristics are a combination of all these streams. The wastewater characteristics of along the secondary and tertiary treatment line appear in table 3:

Table 3

Wastewater Characteristics at the different Stages of Treatment

	Balancing Tank	Final Settlement Tanks	Tertiary treated effluent
COD mg/l	2600	87	60
BOD^5 mg/l	890	10	7
Suspended Solids mg/l	1780	30	7
NH^3-N mg/l	121	0.5	1.4
NO^3-N mg/l	14	4.8	5.4

Sludge Treatment

Sludge is wasted on a daily basis in order to maintain the appropriate MLSS concentration in the aeration tanks which is also monitored on a daily basis. The excess sludge is wasted from the final settlement tanks at a concentration of approximately 0.8 per cent solids of which about 55 per cent are volatile.

The wasted sludge is then pumped into two picket-fence thickeners where the solids are concentrated to approximately 4 per cent solids and then is forwarded to the digesters. The digesters operate in series and, therefore, the sludge is first pumped into the first digester from where it overflows in the second.

The solids concentration in the digester 1 is reduced to about 2.8 per cent while after the second digester is further reduced to 2.6 per cent. Following the digestion the sludge is pumped into two (one-duty, one stand-by) centrifuges where with the addition of polyelectrolytes the sludge is dewatered to a solid content to an average of 23 per cent.

The dewatered sludge via a screw conveyor is disposed into a trailer and is then laid in piles on a concrete platform for further drying prior to its disposal on the fields. Currently the digested sludge produced is about 4,400 kg DS/day.

Since this sludge is finally used as a soil conditioner and since the treatment plant also treats industrial wastes it is closely monitored in order to ensure that it does not contain any contaminants that could cause problems either to the crops, the animals that feed on them or the soil. Typical analysis of this sludge appears on table 4 below:

Table 4
Dewatered Sludge Characteristics

N%	3,75	Cu ppm	202
P%	1,97	Cd ppm	3,47
K%	0,26	Ni ppm	32
Organic Matter %	67,33	Pb ppm	70
Na%	0,36	Cr ppm	133
B ppm	71,0	Fe ppm	11880
Zn ppm	1173	Mn ppm	156

Water Reuse

The treated effluent after chlorination flows by gravity in the 280.000 m^3 storage lagoon from where via two pumping stations is distributed to 55 ha of land for the cultivation of mainly alfalfa. The lagoon volume has been designed to balance the produced treated effluent over a 12 month period and is lined with 1mm HDPE membrane. Most of the demand is between April and October (dry season) and, therefore, in winter when the water demand is minimum there is adequate capacity in order to store the produced treated effluent.

The quality of the stored effluent is regularly monitored in order to ensure that its quality is always to the required standard.

Typical reused water characteristics appear on table 5:

Table 5
Characteristics of Stored Effluent.

Conductivity ds/m	3,2	pH	8,3
Chlorides ppm	500	Sodium	590
Sulphates ppm	427	Potassium	70
Carbonates ppm	Nil	Calcium	88
Bicarbonates ppm	670	Magnesium	29
Nitrates ppm	14	Boron	1,25
Iron ppm	0,2	Lead	0,02
Zinc ppm	0,11	Cadmium	Nil
Manganese ppm	0,03	Nickel	0,001
Copper ppm	0,01	Chromium	Nil

One of the distinctive characteristics of this reused water is its high conductivity as compared to the ordinary sewered sewage. The reason for this is the fact that the domestic septage is collected from the absorption pits where salts may got concentrated with time or because more salts are dissolved from the soil. One of the main reasons of the decreasing permeability of the absorption pits is the accumulation of fats which block the soil pores. So a number of households in order to reduce the frequency of emptying their pits add in them caustic soda, which dissolves the fats. This caustic soda will naturally be tankered to the treatment plant when the time comes for the absorption pit to be emptied.

Another reason for this high conductivity is the fact that industrial wastes are saline due to the processes of production. For example, most food industries use caustic soda for sanitation purposes while the other industries use salts of some type or another which invariably increase the conductivity of their wastewater. Eventually the combined conductivity of all treated wastewater is 3,200 μs/cm. This relatively high conductivity is of concern to the agriculturists and has limited the use of the treated effluent to crops which are relatively resistant to salinity such as alfa-alfa, and has excluded its use for the irrigation of trees such as citrus.

Cost of Implementation of the Project

The treatment plant cannot be considered as a low cost project. It is highly sophisticated using the latest technology and the contract was awarded for the price of $16 million. Further to the capital cost the company which has undertaken its design and construction has also undertaken its operation for the first five years. The operating cost for this period is approximately $4 million.

Although it is an expensive and highly sophisticated plant nevertheless it is the cheapest and quickest possible solution to a problem that if it was to follow the normal and accepted procedures (construction of sewerage networks and sewage treatment plants) would have taken years and been substantially more expensive in view of the fact that the sources of the wastes are scattered (villages and individual industries) and no single network and treatment plant would have been able to serve them.

Financing of the Project

The project has been wholly financed by the Government of the Republic of Cyprus. However, as a matter of policy the government intents to impose discharge charges to those who use the treatment plant.

Regarding the domestic septage the tanker drivers will be charged per cubic meter and in turn they are expected to transfer this cost to the residences they serve. For the discharge of the industrial wastes the industries shall be charged directly by the government.

The policy of the government is to impose such charges so as to cover the capital expenditure in a period of 20 years with an interest rate of 8, 5 per cent and at the same time cover its operational costs. However, for the purpose of calculating the rates from the capital cost of the plant the following have been deducted :

- **Cost of tertiary treatment:** The policy of the government is to pay for the cost of the tertiary treatment and at the same time resume ownership of the treated effluent, so as to use it where and in the manner that is most appropriate.
- **Value equal to 30 per cent of the cost required for the treatment of industrial wastes:** The government in order to encourage industries in building their own treatment plants has introduced a subsidy of 30 per cent on the capital cost for those industries that construct their own treatment plant. Therefore, in order to place all industries on the same basis the same percentage has been deducted from the cost of the plant that relates to the treatment of these wastes.

In order to distribute the cost of construction and operation as fairly as possible between the users it was attempted to separate the construction costs and the operation costs for each category of waste. Then a set of formulae was developed and the cost per cubic meter of wastewater per category was determined. Two basic formulae have been derived : one for the construction costs and one for the operational expenses. These formulae are as follows:

a. Construction Cost

$$\mathrm{CONCOST}/\mathrm{M}^3 = \mathrm{G} + \mathrm{M} + \mathrm{F} + \mathrm{S} + \mathrm{D} + \mathrm{T} + \mathrm{B}.\left(\frac{\mathrm{COD_{in}}}{\mathrm{COD_{base}}}\right)$$

where:

$\mathrm{CONCOST}/\mathrm{M}^3$ = Construction Cost per cubic meter of wastewater. This includes all civil and electromechanical costs.

G = Capital cost of all units used by all types of wastes, i.e. infrastructure (roads, electricity supply etc), balancing tanks, secondary treatment etc.

M = Capital cost for the pre-treatment of metal wastes.

F = Capital cost of pre-treatment of FOG wastes.

S = Capital cost for the pre-treatment of strong organic wastes.

D = Capital cost for the pre-treatment of dairy wastes.

T = Capital cost of tertiary treatment.

B = Capital cost of secondary and sludge treatment.

COD_{in} = COD of incoming wastewater (mg/l).

COD_{base} = Average COD of domestic septage and weak organic wastes.

b. Operational Cost

$$COST/M^3 = R + V1 + V2 + V3 + V4 + V5 + B.\left(\frac{COD_{in}}{COD_{base}}\right)$$

where:

$Cost/m^3$ = Operational cost per cubic meter of wastewater.

R = management costs.

V1 = Operational cost for the treatment of metal wastes.

V2 = Operational costs for the treatment of FOG wastes.

V3 = Operational costs for the treatment of SOW.

V4 = Operational costs for the treatment of dairy wastes.

V5 = Operational cost for balancing, pumping etc.

V5 = Operational cost for tertiary treatment.

B = Operational cost for secondary treatment and sludge treatment.

COD_{in} = COD of incoming wastewater (mg/l).

COD_{base} = Average COD of domestic septage and weak organic wastes.

Using the above formulae and the available data, the different coefficients were determined. Using these coefficients the cost per cubic meter of each category of waste and, therefore, the billed value is determined.

As it can be seen from these formulae the cost per cubic meter is both a function of flow as well as a function of load (COD). The cost (construction and operational) apart for the secondary and sludge treatment is a function of flow. Secondary and sludge treatment is a function of load (COD concentration) and is calculated having determined the coefficient "B" and the ratio of COD of the incoming wastewater to that of the domestic septage and weak organic wastes.

Conclusion

The above described treatment plant has used the latest available technology for the treatment of wastes from many sources and various characteristics. As a design is reasonably complicated and it requires competent personnel to operate it. Although not cheap it is believed to be the only way to address a problem that has increased over the years and solving it in the traditional way it would take many years and significantly more money.

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2
Waste Stabilization Ponds

Stabilization pond is also known as oxidation pond and has been in use as a method of wastewater treatment for domestic sewage as well as industrial wastes for decades. The term stabilization pond is more appropriate as compared to oxidation pond since stabilization of organic matter present in the wastewater takes place rather than mere oxidation. This system comes under the category of low cost waste treatment systems.

Waste stabilization ponds are in use in India as a simple and reliable means of sewage and industrial waste treatment. It provides treatment at a fraction of the cost of conventional biological treatment system such as activated sludge system. Its effectiveness in treatment as also lower cost both capital and O&M, makes it possible to bring sewage treatment within the scope of smaller communities and at the same time, it helps to reduce the pollution of rivers and streams.

First stabilization pond was provided for sewage treatment in Madras University Campus during 1957. The first large scale waste stabilization pond was constructed at Bhilai Steel Plant to treat sewage contributed by a population of 1,00,000. Later on, number of ponds were constructed in Ahmedabad for the treatment of city sewage. Subsequently, stabilization ponds were constructed and are in operation at several places in India. The reasons for its popularity being easy operation and maintenance, cheap construction, absence of skilled supervision and its efficiency which is well comparable to other treatment systems.

The waste stabilization pond system may be used as an alternative to high rate biological treatment system for removing dissolved and colloidal biodegradable organic material. Wastewater constituents removed by the system include BOD, COD, TOC and specific soluble organic materials proven to be biodegradable such as phenol.

Other waste constituents such as ammonia, suspended solids and certain heavy metals will also be removed by the ponds, but usually are not a primary reason for its application.

Definition

The term waste stabilization pond is applied to a body of wastewater employed with the retention of wastewater or organic wastes until the wastes are rendered stable and inoffensive for discharge into stream through physical, chemical and biological processes involving the action of algae and bacteria under the influence of sunlight and air.

Process Mechanism

As the definition says, the process of waste stabilization in a stabilization pond depends on the action of algae and bacteria. There exists a "Symbiotic Relationship" or mutually beneficial relationship between algae and bacteria (**Figure 1**).

The bacterial decomposition releases carbondioxide (CO_2) as an end product which is utilized by the algae in presence of sunlight for the synthesis or poliferation of algal cells. While doing so, the algae release oxygen. This oxygen, in turn, is utilized by the bacteria for the decomposition of organic matter. It is estimated that approximately 1.6 mg of oxygen is released by the algae per mg of dry organic cell material synthesized. The process mechanism is depicted in **Figure 2.**

The success of the process depends on two major factors: (1) enough sunlight (solar energy), and (2) enough detention time for the bacteria to finish their job of stabilization. The amount of sunlight depends on (a) surface area of pond, (b) solar radiation at a particular altitude and latitude, and (c) number of non-rainy days. The stabilization pond as a treatment will not be feasible at places where rainfall takes place for major part of the year and sunshine is scanty such as islands of Andaman or Lakshadweep.

Pond Ecology

An aerobic or facultative pond typically contains abiotic substances, producer organisms, consumer organisms and decomposer organisms. The plants are producer organisms, mainly bacteria and algae. These microscopic plants are capable of synthesizing protein,

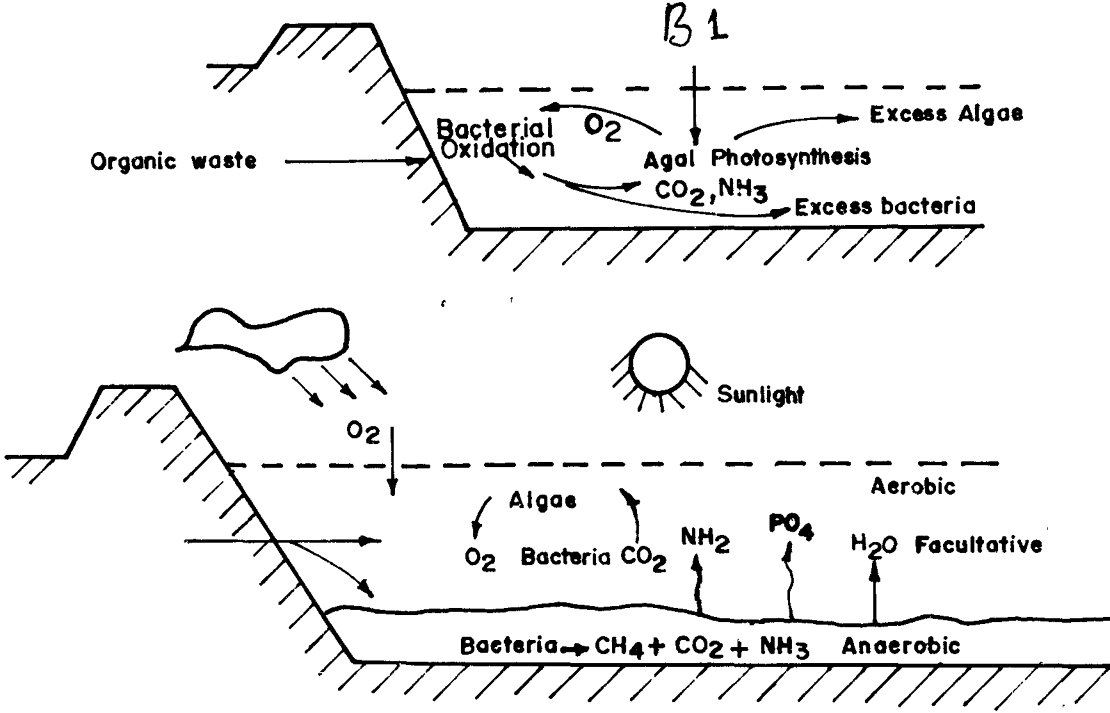
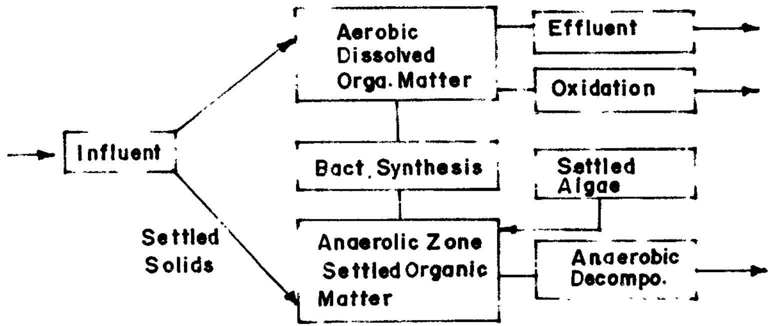


Fig. 1 : Process Mechanism in Waste Stabilization Pond



Aerobic

$$CH_2O + O_2 \xrightarrow{\text{Bacteria}} CO_2 + H_2O$$

(Oraganics)

Anaerobic

$$2CH_2O \xrightarrow{\text{Bacteria}} CH_3COOH \xrightarrow{\text{Bacteria}} CO_2 + CH_4$$

Algae in Turn Reuse the Corbon (CO_2) to form Algal Biomass

$$CO_2 + 2H_2O + \text{Energy} \xrightarrow{\text{Algae}} CH_2O + O_2 + H_2O$$

Fig. 2 : Process Reactions in WSP

ingesting and digesting synthesized organic substrate. The decomposer organisms mainly fungi, reduce organic material by extracellular digestion and create basic intracellular inorganic constituents through metabolic pathways.

The major biological reactions which occur in waste stabilization ponds include: (a) oxidation of carbonaceous organics by aerobic bacteria, (b) nitrification of nitrogeneous material by bacteria, (c) reduction of carbonaceous organics by anaerobic bacteria living in benthal deposits at bottom liquid, and (d) oxygenation of surface liquids by algae.

For biodegradable wastewaters, the weight of cells produced is roughly equal to 0.5 and 0.6 times, respectively, the weight of chemical oxygen demand (COD) and biochemical oxygen demand, 5 day at 20°C (BOD_5) removed.

A facultative pond can provide an anaerobic environment near the bottom, buffer zone throughout the middle, and an aerobic zone near the top liquid surface. Therefore, it is necessary to provide enough surface area for photosynthetic oxygen to take care of the initial soluble BOD plus that released by the anaerobic decomposition and to compensate for any chemical oxygen demand.

Algae: It is a green floating scums or green masses. The algae possess internal green pigment called as chlorophyll which in the presence of sunlight combine with water and CO_2 to form starch and release oxygen. Chlorophyta is called as green algae while cyanophyta is called as blue-green algae.

Typical of the green algae in facultative waste stabilizaton ponds are *Chlamydomonas, Chlorella,* and *Euglena.* Blue-green algae common to waste stabilization ponds are *Oscillatoria, Phormidium, Anacystis* and *Anabena.* In the operation of pond, *Chlamydomonas* and *Euglena* are generally the first planktonic genera to appear. Blue-green algae mats frequently develop in ponds during the summer and usually rise to the surface. Problems develop when detached patches of benthic algae such as *Phormidium,* begin to accumulate. *Euglena* show a high degree of adaptability to various pond conditions and are present during all seasons and under most climatological conditions.

Frequently, *Euglena* and *Chlamydomonas* tend to dominate during winter season, while the various *Chlorococcales* are most numerous during summer months.

Animal in waste stabilization ponds consist of photozoans, notifers, worms and larvae. The latter two are found in bottom of pond. The distribution of animal population may be seasonal and highly subject to variety of environmental conditions.

Performance of Waste Stabilization Ponds

The overall performance of the pond system is highly temperature dependent. The settled sludge at the pond bottom will be degraded by anaerobic bacteria and throughout most of the pond depth, the soluble BOD will be biodegraded by facultative bacteria. Thermal stratification of the pond contents is sometimes responsible for maintaining separate aerobic and anaerobic zones for extended period of time. Thus, the performance of the pond is affected by the relatively slower biodegradation rates of anaerobic facultative system in contrast to the more rapid rates exhibited by truly aerobic facultative systems.

The optimum temperature range for effective performance is 30-35°C.

Design Considerations

For getting the desired effluent quality from the stabilization pond, it is necessary to have proper planning which will result into minimum cost of construction as also minimum cost of operation and maintenance.

The important parameters for design are:

1. **Quantity of Waste to be Treated :** Correct assessment of the quantity of wastewater should be done well in advance. For the existing system, this can be done by actual flow measurements. In case of domestic sewage, the quantity of sewage to be treated can also be estimated from the water supply and population figures. For future expansion in case of industry, proper allowance can be made and in case of sewage, population projections at the end of design period can be made and quantity be estimated. For the proposed industry, data from similar type of industry can be made use of.

2. **Nature of Waste :** This is another important consideration since the pollutional load depends on type of waste and the source of waste. The important parameters to be assessed

are pH, SS, BOD_5(20°C), toxic substances, temperature of waste and the 'K' value which is called as pond removal rate constant or BOD degradation rate per day at 20°C.

'K' value vary from waste to waste and also for similar type of waste it differs as shown below :

Type of Waste	**'K' Values/d (20°C)**
Domestic Sewage, Mumbai	0.122
Domestic Sewage, Ahmedabad	0.106
Textile Waste	0.150
Domestic Sewage, Kanpur	0.125
Domestic Sewage, Delhi	0.186
Milk Bottling Waste	0.190

The required detention time of the pond can be estimated from the equation,

$$T = 1/K \text{ Log } L/(L-Y)$$

Where,

t - Detention time in days.
K - Pond removal rate constant/day at 20_oC.
L - Kg of BOD load applied/day.
Y - Kg of BOD load satisfied or removed/day.

At other temperatures,

$$K_T = K_{20} \ (1.04)^{T\ 20}$$

3. **Cloudiness :** The sky clearance factor affects the amount of solar radiation received at a pond surface.

$$\text{Average Radiation} = \text{Minimum Radiation} + [\text{Max-min radiation}] \times \text{sky clearance factor}]$$

There are standard values of solar radiation which are reported for an average of 75 per cent of sky clearance. Indirectly it means that 75 per cent of the time in a year, sky will be clear with no clouds or rainfall.

4. **Organic Loading Rate :** The organic loading rate or BOD loading rate is expressed as kg of BOD/hectare/d.

5. **Nutrients :** As for other aerobic biological treatment system, the waste stabilization pond also requires presence of adequate nutrients in the proportion of 100 (BOD) : 5(N) : 1P. Except

sewage, other wastewaters, if are devoid of N and P, these are added externally for effective functioning of the system.

General Features of Waste Stabilization Ponds

Location of the Pond

The site selected for stabilization pond should be :

(a) Favourable to wind direction such that (i) there is no odour problem for the nearby residential locality, and (ii) natural wind induced mixing of sewage in the pond is maintained.

(b) Minimum 400 metres away from the nearest residence and 20 metres away from drinking water wells

(c) Suitable for excavation (natural depressions, if available, should be made use of)

Constructional Details

(a) Pond Bottom

Pond area should be cleared of all vegetation and debris. Pond bottom should be made as level as possible. The ground levelling obtained by earth-moving equipment like a bulldozer or a grader will usually be sufficient. Soil formation for the bottom should be relatively impervious to avoid percolation and ground water pollution as far as possible.

(b) Embankment

Vegetation and debris should be completely removed from the area upon which the embankments are to be constructed. Embankments should be constructed of impervious materials as far as possible and completed sufficiently to form a stable structure.

(i) Top width	–	Minimum top width should be 1.5 m.
(ii) Slopes	–	Outer slopes of embankment may be made with slopes ranging from 2.0-2.5 horizontal to 1 vertical.

(c) Flood Protection

Possibility of floods should be considered as earthern embankments would be subjected to damage by floods

(d) Inlet Arrangement

The sewer line arriving at the pond is generally made to terminate in an inlet chamber, where coarse bar screens and

'V' notch for measurement of flow may be provided. Inlets may be provided at a distance of 15 metres from the sides. If possible multiple inlets may be provided. Inlet arrangement should be such that incoming waste is not discharged in the direction of the outlet, thus, encouraging short circuiting. Directly below the inlet pipe bend, concrete or masonry platform, may be provided to act as a splash pad and prevent erosion particularly in the initial period when the pond is not filled.

(e) **Outlet Arrangement**
The outlet may be in the form of a pipe or suitable length of weir. In either case it is very desirable to provide baiffle (extending to about 20 cm into the pond and 15 cm to 30 cm above the pond water level depending upon the expected wave action) to prevent floating scums as well as algae from passing out with the effluent.

(f) **Fencing**
The pond area should be enclosed with a suitable fence to prevent entrance of livestock and discourage tresspassing.

Operation of Ponds

(a) **Starting of a New Pond**
After the pond construction is completed, raw waste may daily be fed slowly such that a level of 15 cm is maintained, till such a time that algal growth establishes itself naturally.

(b) **Routine Operation and Maintenance**
Operation and maintenance is a matter of "good house keeping." Odour and colour of the pond should be noted daily. Accumulation of floating algal scums along with dead leaves at the corners and sides of the ponds as well as growth of grass and weeds at the water margins should be checked. Some useful tests to be conducted daily include (I) BOD of effluent, (ii) pH, and (iii) microscopic examination for algae.

Absence of Health Hazards

Properly designed, operated and maintained ponds are free from odour, fly and mosquito nuisance. A properly designed and operated pond will give an equally good effluent as the conventional biological waste treatment plant.

Problems and Solutions on Malfunctioning of WSP

1. Surface Conditions

Condition of WSP	Resulting problem	Solution
Algae growth	Odours, less efficient pond performance	Breakup mats
Scum layer	Odours, insect breeding	Breakup mats
Sludge that rises	Severe odours	Breakup mats
Floating debris	Interference with outlet	Remove debris

2. Pond Colurs

Pond type	Chara. colour
Anaerobic	Grayish black
Facultative	Green or brownish green
Maturation	Green

3. Frequency of Sludge Removal

Anaerobic pond	2-12 years
Facultative pond	8-20 years
Maturation pond	5-10 years

Laboratory Facilities

A small laboratory may be provided with facilities for tests required for routine operations. Or otherwise any existing chemistry laboratory can be made use of for routine or occasional tests by addition of few essential equipments and glassware.

Effluent Utilization

Effluent should not be as far as possible, disposed of into the adjacent water course. If land could be acquired as anticipated, effluent can be used for irrigation of essential oil bearing plants like Hentha or citronella. Acreage required would be dependent upon waste quantity available.

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3
Aerated Lagoon

Working Aspects

The aerated lagoon is generally an earthen basin having a depth of 2.5 m to 3.5 m of wastewater which is aerated either by diffused air or by mechanical surface aerators. The surface aerators may be of floating type installed on floats or of fixed type supported by columns and beams.

Raw wastewater is fed to the lagoon after pre-treatment in screen and grit chamber but without presettling. The lagoon acts as a storage-cum-aeration basin in which artificial aeration replaces the algal oxygenation of waste stabilisation ponds. Detention time of 3 to 5 days or more is provided depending upon the type and strength of waste. BOD removal efficiencies of 70 to 90 per cent can be achieved.

As regards its cost, the aerated lagoon lies in between the oxidation pond on one hand and the oxidation ditch and conventional activated sludge on the other. It has, therefore, good potential for its use in India especially for middle sized towns. It can also be employed in the treatment of industrial wastes like pulp and paper, sugar, tannery etc.

Power Requirement

Power consumption in aerated lagoon is so kept that the turbulence level is just sufficient to ensure effective distribution of oxygen throughout the lagoon contents but may be insufficient to keep the solids in suspension. As a result, a certain amount of settlement of solids does occur at the bottom of lagoon where the solids may go anaerobic decomposition. This is analogous to waste stabilisation pond. If the turbulence level in the lagoon is increased to maintain all solids in suspension, the system would become similar to activated sludge system or extended aeration system which will need settling and sludge return. This is avoided in aerated lagoon.

Sludge

In aerated lagoon, the solids which settle at the bottom undergo anaerobic decomposition and as such the net sludge production is much less. Due to the depth of lagoon which is more than in oxidation ponds, the sludge deposition may not pose any problem as long as grit is removed and screening of raw sewage is done regularly. The lagoon should be desludged after 4-5 years or else it will affect the settling of solids and subsequently carrying of the solids in the effluent would take place.

Types

Aerated lagoon is of major two types: (i) Aerobic, (ii) Aerobic-anaerobic. In aerobic type, the solids are maintained in suspension so that the effluent suspended solids will be equal to solids in the basin. In most cases, separate sludge settling and disposal facilities are required. The aerobic basin is readily acceptable as modification to the activated sludge process.

In facultative type, the mixing level is low enough to allow the organic solids to settle but high enough to distribute the dissolved oxygen throughout the lagoon. As such, power levels are much less than in aerobic type.

In view of the high power levels and requirement of clarifier, aerobic lagoons are normally not employed in sewage treatment.

Advantage and Disadvantages

Advantages

1. Relatively low operating and capital costs.
2. Low operating skill requirements, less land is required compared to oxidation pond.
3. A high quality effluent is obtained with solids separation.
4. At low loading rates, the biological solids are relatively stable.
5. Resistance to upsets.
6. Ability to treat high strength wastes.

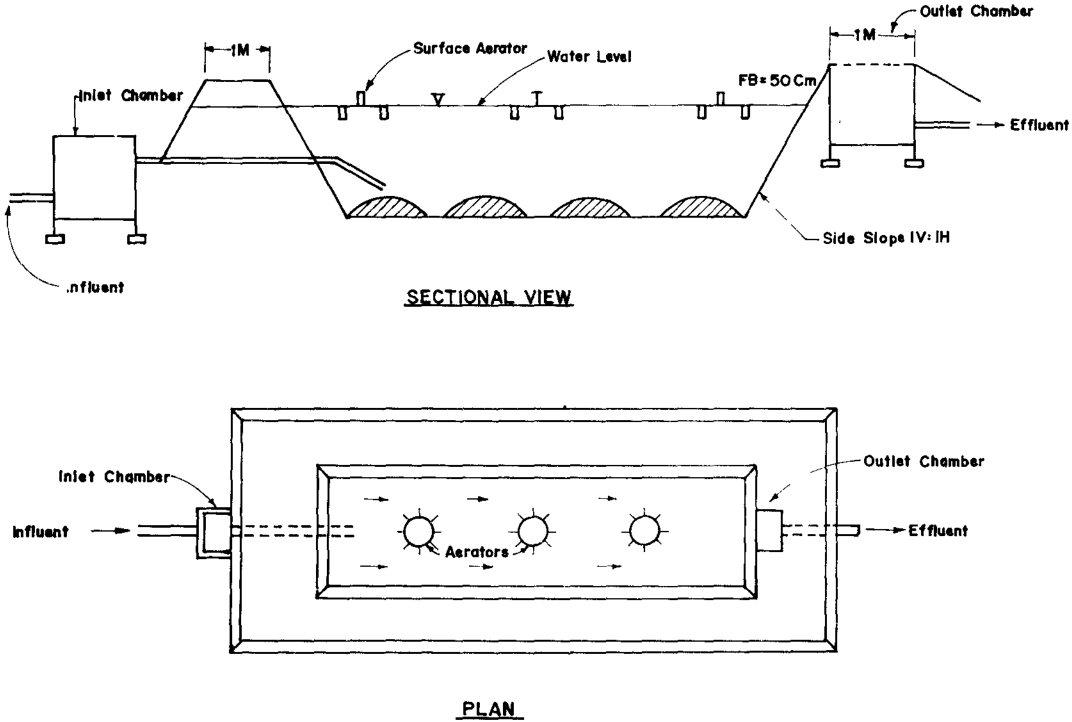

Figure 1 : Schematic Diagram of Aerated Lagoon

7. Provides buffering action when pH is a problem.
8. Relatively large heat transfer when treating high temperature wastes.

Disadvantages

1. More land is required as compared to ASP.
2. More staff for O and M as compared to oxidation ponds is required.
3. Extra care is required to be taken during construction to achieve watertightness.

Design Factors

1. Aeration time which in turn depends upon: (a) nature of waste, (b) temperature of lagoon, (c) desired treatment efficiency, (d) nutrients.
2. Aeration system and its Capacity: (a) oxygen required for bioxidation, (b) type of equipment and its performance, (c) oxygen transfer characteristics.

System Rate Constant (K/day)

The rate at which BOD is satisfied with time can be determined experimentally for a particular temperature at which the lagoon will be called upon to function. This rate is called as system rate constant.

Treatment efficiency of aerated lagoon in time t is given by $\frac{Le}{Li} = 10^{-kt}$

Where Le = Effluent BOD, mg/1
Li = Influent BOD, mg/1
K = System rate constant per day.
t = Time in days.

On simplifying, the equation becomes

$$\log Le = \log Li - kt$$

The equation is in the form of straight line equation Y = mx + c. The value of K can be found out for a waste by experimentation and plotting the graph log BOD remaining versus time in days. Slope of Straignt line gives k value. For other temperatures $K_T = K_{20}(1.035)^{T\,20}$

Aerated lagoon is designed with sufficient detention time and aeration to work efficiently even in the worst condition, i.e. winter.

Desired Treatment Efficency

Adequate detention time and aeration has to be provided to obtain desired treatment efficiency depending on nature of waste and temperature of operation. BOD removal efficiencies of 70 to 90 per cent may be obtained although the effluent may exhibit slightly turbid appearance due to S.S. concentration. Provision of clarifier and sludge return is not necessary but the lagoon can be followed by a shallow pond, if desired, which may further help in removal of solids and BOD.

Factors Affecting Performance

Major factors those affect the organic removal efficiency of aerated lagoon are: (1) Temperature, (2) Nutrients, (3) Toxic elements and heavy metals, (4) Staging of lagoons.

Temperature

As in the case of other biological treatment systems, the activity of microorganisms gets affected by temperature. Temperature of the lagoon may vary during different seasons of the year. However, the degree of variation will be less as compared to ambient temperature. For the same influent BOD and detention time, the organic removal efficiency will be higher in summer months than in winter months. Moreover, the degradation of organic matter by the bacteria progresses at a slow rate during colder temperatures. Therefore, the aerated lagoon need be designed to take care of worst possible condition, i.e., winter months.

Nutrients

It is known that bacterial decomposition progresses well when adequate nutrients such as nitrogen and phosphorus are available in the wastewater. The desirable proportion of nutrients is for every 100 Kg. Of BOD there should be 5 Kg of nitrogen and 1 Kg. Of phosphorus for aerobic biological treatment system. Many industrial wastewaters do not contain enough nutrients to satisfy the above proportion and in such cases, nutrients are required to be added externally by adding urea and super phosphate for satisfying N and P requirements.

Toxic Elements and Heavy Metals

The presence of toxic elements/compounds such as phenol, cyanide etc. may have adverse effect on the microbial degradation in the lagoon. Similarly, the heavy metals such as chromium (hexavalent), zinc etc. may slow down the rate of biochemical reactions in the lagoon. Therefore, these constituents must be removed by physics-chemical treatment methods.

Effect of Staging

The aerated lagoon can be operated as a series of n-smaller lagoons in series. The optimal condition is to maintain equal volume per lagoon. Operation of smaller aerated lagoon in series does not only reduce the lagoon volume requirements but also the power required for mixing. Therefore, it is desirable to construct 2 aerated lagoons in series instead of one lagoon with bigger volume. From construction, operation and maintenance point of view also, two lagoons in series are better than one single lagoon.

Construction Details

Areated lagoon is generally constructed in earth work with sloping sides. The sides have either IH:IV or IH:1.5 V slope. To avoid leaching from sides and bottom, the sloping sides are always provided with stone pitching or concrete pre-cast slabs and the bottom is made impermeable by putting layers of clay puddles and compacting it.

The site of lagoon should be as far as possible located in impervious soil so as to avoid problem of groundwater percolation. The depth of lagoon varies from 2.5 to 3 m with 50 cm as freeboard. Inlets and outlets are located on opposite sides of the lagoon.

When fixed type of mechanical surface aerators are used for oxygenation, the supporting columns and beams are constructed in sturdy cement concrete to withstand vibrations. The alignment of aerators should be uniform and equidistant placement must be assured. The submergence of aerators in the lagoon contents should be uniform and within 10 cm to 15 cm for achieving desired mixing levels and turbulence.

The inlet pipe of lagoon must be submerged to avoid odours and short-circuiting while the outlet can be in the form of a weir over which the treated effluent can pass over. To avoid splashing action, the weir should be placed within a stilling chamber.

The water level in the lagoon should be adjusted so as to ensure gravity flow conditions without the need of pumping. As far as possible, the aerated lagoon should be followed by polishing pond (an earthen basin) with 1-2 days detention time. This will not only provide polishing treatment but also will result in BOD removal due to photosynthetic activity.

Design Procedure

1. Design the pretreatment units first.
2. Estimate the k value from the experimental data.
3. Work out the detention time for the desired treatment efficiency.
4. Estimate oxygen and power requirements.
5. Provide a minimum of two aerators. Spacing of aerators to be kept uniform and at equal distance.
6. Decide side slopes depending on soil conditions.

Operation and Maintenance

Starting a new plant : Before starting a new plant, all the lagoon walls and bottom and the pipes to be checked for watertightness. Grass and weeds growth should be removed from the lagoon and sides. All the mechanical equipment be checked and seen that it is in good working order. It should be properly lubricated.

The lagoon is filled with wastewater (pretreated) upto the liquid level and aerated continuously. In order to speed up the biological solids formation, sometimes seed is introduced. To confirm the presence of D.O., samples are withdrawn and tested for D.O. After a period of 10-15 days, the lagoon is ready for operation.

Maintenance

1. The bottom and sides of lagoon should be watertight and periodically checked for percolation.
2. Submergence of the blades of surface aerators should be checked and kept at uniform level.
3. Lagoon has to be desludged every 4-5 years or else it will reduce effective atorage capacity

4. Proper anti-corrosive paints preferably 'epoxy based' should be applied to all metallic structures.
5. Periodic maintenance of all interconnecting pipes should be done. Periodic maintenance of sewers has to be done to remove deposits accumulating on inner surfaces of sewers.
6. Inter-connecting drains and cut off trenches should be made to direct the surface runoff from the lagoons.
7. Systematic and regular monitoring of the performance should be carried out. The basic parameters to be monitored are pH, D.O., BOD, COD, solids, nitrogen and phosphates in the raw as well as treated wastewater. Occasional D.O. measurements at different points and depths should be done to ensure aerobic conditions.

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4

Oxidation Ditches

Oxidation ditch comes under extended aeration system which works on activated sludge principle with the only difference that the wastewater is a aerated for a longer time of 16-20 hours and the sludge obtained is well mineralised, the effluent quality being superior as compared to other aerobic biological treatment systems.

Advantages

- No need of primary settling tank.
- Longer aeration time or HRT which enables complete mixing in the ditch.
- Low organic loading rate (F/M). Efficiency of the system is more.
- Quantity of sludge produced is less.
- Quality of sludge is such that after sun drying the sludge can be disposed off without sludge digestion.
- Operation is simple since no PST and digester is required.

Basic Requirements

- High MLSS concentration need to be maintained.
- Oxygen requirement is more consequently more input power for oxygenation.
- More operation and maintenance cost.

Working Mechanism

Oxidation ditch works on the principle of extended aeration. Oval shaped endless ditch serves as aeration tank. Aeration is carried out by means of horizontal moving rotors.

The channel may be earthen, concrete or brickwork with impermeable bottom. The earthen section will be having sloping sides with stone pitching.

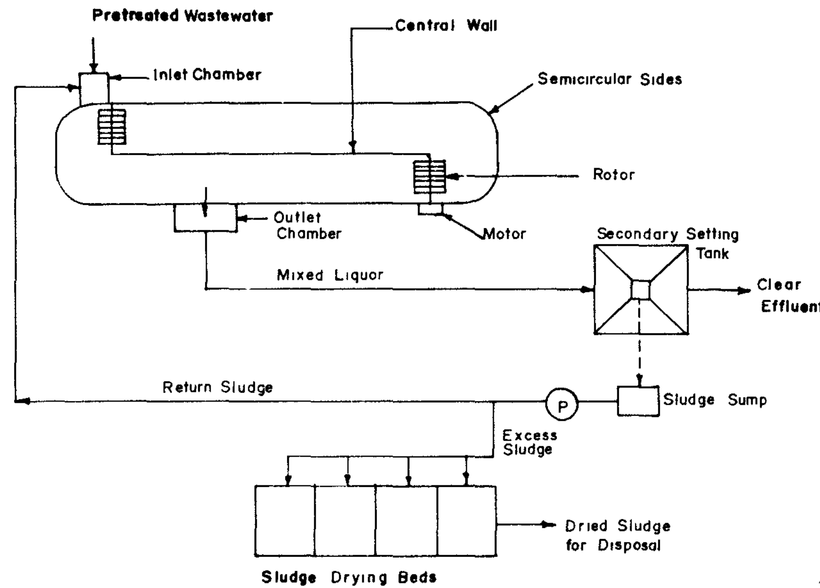

Figure 1 : Schematic Diagram of Oxidation Ditch

As the rotors move, the wastewater gets aerated and as a result certain velocity is also created in the contents. The aeration rotors are normally of cage type and rotate at a speed of 70-80 rpm with the 16 cm depth of immersion. Under standard test conditions, one meter length of rotor imparts 2.8 kilograms of oxygen per hour.

Based on the total input organic load, loading rate is decided, rotor length is estimated and width of the ditch is decided to accommodate the rotor. The rotors have 15 to 30 cm clearance from the walls on which they are placed on bearings.

Inlet and outlet are located just opposite to each other. Baffles are provided at the outlet to avoid rising of water level in the ditch appreciably. Recirculation arrangement is provided to maintain desired MLSS in the ditch. Oxidation ditch is followed by secondary settling tank from where sludge is collected in sump and recirculated back in to the ditch with the help of a pump.

Operational Variables

Important operational variables are maintenance of F/M and MLSS concentration. MLSS can be controlled by adjusting return sludge based on sludge volume index. SVI can be determined experimentally.

Operational Problems

Sludge Bulking

This is indicative of poor settling of sludge. This results in poor quality of effluent and rapid loss of MLSS from the aeration tank. It is due to insufficient air supply, low pH or septicity and due to growth of filamentous organisms. This phenomenon can be controlled by eliminating the causes and chlorinating the return sludge.

Sludge Rising

This happens due to formation of nitrogen gas bubbles which lifts the sludge on the top layers. This phenomenon may be due to denitrification taking place in settling tank. the problem can be overcome by (1) increasing return sludge rate, (2) increasing the speed of scraper, and (3) increasing sludge wasting rate.

Construction Details

The ditch may be constructed in rubble or brick masonry plastered with cement mortar on both sides. The foundation and thickness of wall etc. depend on local soil conditions. The floor slab of the ditch, if necessary, due to local conditions shall be in reinforced concrete with nominal reinforcement and expansion joints etc. All the civil structures should be water tight.

The raw wastewater will be pumped to the oxidation ditch since the ground contours may not be favourable for gravity flow. When pumping is being done consideration is given to the desired water level in the ditch and its settling tank effluent launder so as to be able to command the irrigation area, thus avoiding double pumping. This may result in the water level of the ditch being 0.3 to 1.0 m or more above the surrounding ground level. Adequate free board of 0.3 to 0.6 m may be provided above the water level. In any event the top of the walls of all tank structures should be sufficiently above the surrounding ground level so that storm run-off may not enter the ditch. The side wall adjacent to the motor and gear units should be raised sufficiently to prevent the wetting caused by the splashing of wastewater in the vicinity of the rotor.

The Oxygenation Rotors, Motor and Gear : The assemblage of motor gear unit with the rotor of the ditch is important. This could be done either by direct flanged-coupling with the shaft of the rotor or by chain pulley or belt driven system. Where the width of the ditch is quite substantial the rotor will need intermediate supports. Suitable bearing are necessary to be mounted on every support. For rotors of long lengths hollow pipe shafts may be used instead of solid shafts. Since the rotor is the main item of the equipment which is liable to attack by corrosion and, therefore, minimum thickness of all components should be 6.3 mm. It will also be desirable to coat them with an epoxy or other suitable anti-corrosive paint or lining.

Inlet and Outlet : The inlet to the ditch can be by a gravity pipe discharging freely above the ditch water level or by the rising main dipped into the ditch. The inlet should preferably be just upstream of a rotor. For smaller installations, the inlet chamber should be of adequate size preferably in two compartments, one for raw wastewater and the other for return sludge. Both these compartments will be provided with suitable measuring weirs and baffles. For bigger installations conventional flow measurement devices should be provided for both wastewater as well as for return sludge.

The outlet from the ditch leading to the settling tank should be a pipe of sufficient diameter but the outlet itself should preferably be in the form of a weir of sufficient length to avoid undue heading up of wastewater in the ditch particularly during peak flows, as such heading up would affect the depth of immersion of the rotors and consequently the oxygenation capacity.

Bottom Drain Pipe : A drain pipe at the bottom (on the floor) of the ditch is necessary to facilitate draining the ditch contents in case of repairs, maintenance etc. The drain pipe can be made to discharge into the sump well of the return sludge pump house. The drained liquid from the sump can be pumped out and disposed off by means of a Tee to be provided in the delivery main to the ditch. In case the levels permit, the drain pipe can be made to discharge in an adjacent chamber to which gravity pipe line can be laid to join the treated effluent pipe/channel.

Mid-depth Drain Pipe : The development of sludge solids in the early stage of operation of the ditch requires filling up the ditch with wastewater or mixture of wastewater and water; aeration of the ditch contents for about 18 to 20 hours; settling for a maximum of 2 hours and draining of supernatant from surface by 0.3 m liquid depth. For draining the supernatant from the ditch, a drain pipe of adequate size at mid (liquid) depth will have to be provided. The pipe size should be sufficient to discharge 0.3 m of liquid, from the ditch in half an hour to one hour period.

Commissioning of a New Ditch : The first step in order to put the ditch into regular operation is to build up enough microbial solids, mixed liquid suspended solids (MLSS) in the system. The desired MLSS concentration to be maintained in the ditch will be 3,000-5,000 mg/1 with an average of 4,000 mg/1. The steps to be followed for developing the solids are given below :

The ditch may be filled upto 3/4th volume i.e. upto 1.0 m depth with water if available. Thereafter, wastewater may be allowed into the ditch to the operational level of 1.2 m. It water is not available at the site, the ditch may be filled up to the operational level, the aeration rotors will be switched on to aerate the ditch contents for 24 hours. After aeration for this period, the rotors will be put off and ditch contents will be allowed to settle in the ditch for about 2 hours. The supernatant in the ditch will then be reduced by 0.3 m by opening the valve of the mid depth drain pipe.

Thereafter, wastewater will be admitted to the ditch to the operational level and the process described above will be repeated every day till such time that the MLSS concentration in the ditch is attained to a level of about 4000 mg/1. This process of building up of the solids in the ditch will take about 3 to 4 weeks.

Operation : Once the solids, level is reached to about 4,000 mg/1, the ditch is then ready for continuous inflow of wastewater. As the wastewater enters, there will be overflow from the ditch entering into the settling tank. Depending on the design of settling tank it may take about 2 hours to fill the tank. The settled sludge in the settling tank will be taken to the return sludge sump by opening the valve provided on the pipe line between the settling tank and the sump. Opening of valve should be controlled to effect an average flow rate equal to the average flow of incoming waste. This can be ascertained from the measuring weir on the return sludge line leading to the sump. The return sludge from the sump should then be pumped out continuously and put back into the ditch. While this process is on, the liquid level in the settling tank will rise up slowly as the wastewater continuously flow into ditch. The overflow from the settling tank will constitute the treated effluent. As stated earlier, aeration rotors and return sludge pumps in the treatment plant should be operated continuously even if there is an intermittent flow into the ditch.

Excess Sludge Withdrawal and Disposal : With continued operation of the ditch and return of sludge, the MLSS concentration will increase until the capacity of the system to settle and retain the solids is exceeded. If this is allowed to happen, the excess solids will be discharged with the effluent, thus, increasing concentration of the suspended solids and BOD in the effluent. For this reason, it is necessary to withdraw a small fraction of the solids in the mixed liquor and dispose it separately. This excess sludge is withdrawn from the settled sludge which is normally returned to the ditch. Instead of wasting sludge every day, it may be allowed to accumulate for 4 to 6 days and then wasted in one lot. The wasting can be done by opening the valve on the sludge drying beds. If it is necessary, the sludge may also be discharged along with the treated effluent by opening the valve provided for this purpose.

Maintenance : The day-to-day operational requirements may range from regular lubrication of bearings and greasing of reduction gear units of aeration rotor. Flow measurements, sampling, determination of BOD, suspended solids and other characteristics will have to be carried out regularly.

Sampling and Analysis

Tests for BOD on the influent and influent and for suspended solids on the influent, effluent, mixed liquor and return sludge should be carried out regularly and at least once in a week. Frequency of sampling can be increased, if desired. Analysis for nutrients (phosphates, ammonia, nitrite, nitrate etc.) in the influent and effluent will also have to be carried cut periodically.

Maintenance of Records : It is always necessary to maintain proper records. This would help to evaluate the performance of the ditch, and help to furnish useful data when further extensions of the plant is contemplated.

Maintenance of Surrounding Area : A well maintained ditch with properly cleared surroundings and a small patch of garden with appropriate landscaping can convert a waste disposal area into a pleasant spot.

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5
Rotating Biological Contactor

Background

The Rotating Biological Contactor (RBC) is a low cost treatment technology for the treatment of variety of organic industrial wastewaters including domestic sewage. Due to its working on the principle of fixed film process, it has become an attractive alternative for wastewater treatment, particularly for the smaller installations where adequate land area and skilled manpower is not available for operation and maintenance.

Process Details

The rotating biological contactor is an aerobic treatment system and can be conceptually described as a series of circular discs mounted on a horizontal shaft in a open semi-circular cylindrical tank. The discs which are made up of PVC, asbestos, wood, etc. are partially submerged in the wastewater and are continuously rotated with the help of a motor and reduction gear unit so as to provide mixing inside the tank. When the biofilm containing aerobic bacteria sufficiently grows on the surface of the discs, the bacteria attached on the surfaces alternately come in contact with atmospheric oxygen and wastewater. This oxygen is utilized by the bacteria for aerobic degradation of organic matter present in the wastewater. Over a period of time, the thickness of biofilm increases and a stage comes when the biofilm gets detached or sloughed off from the disc surface. The contents of the tank along with sloughed solids are then passed on to settling tank where separation of suspended solids takes places and a clear supernatant is taken for discharge and disposal. The details of RBC are shown in Figure 1.

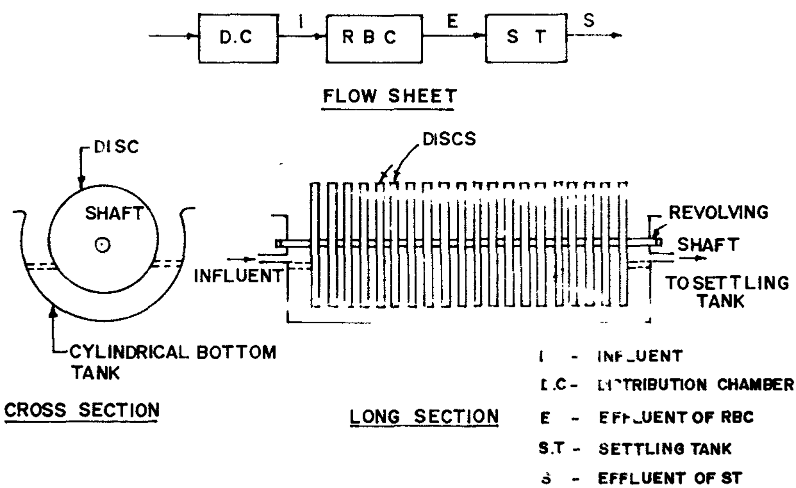

Fig. 1 : Rotating Biological Contactor

Pretreatment

For the RBC process, some sort of pretreatment is required to be provided in the form of grease trap, screen and grit chamber for removal of floating oil, floating objects and gritty material respectively.

Advantages of RBC

The RBC process has several advantages as compared to conventional aerobic biological treatment systems:

1. It is ideally suited for variety of organic wastewaters including domestic sewage.

2. The reactcr volume is very less due to large active microbial population attached on the surface of the circular discs.
3. The large specific surface area (A/V) supporting biomass growth enables operations with long mean cell residence times (MCRT).
4. Biomass retention in the form of thin biofilm allows operation of RBC at exceedingly low hydraulic retention time (HRT) without the danger of cell washout.
5. RBC does not require high energy inputs due to horizontal flow configuration. The power requirement for RBC is much less as compared to conventional activated sludge system.
6. The large growth of aerobic microorganisms on the surface of the media (discs) minimises organic overloading and can withstand shock loads better than other aerobic biological treatment system.
7. RBC process does not require skilled supervision since there is no need to maintain F/M ratio and MLSS concentrations as in the case of activated sludge system.
8. RBC process has minimum operation and maintenance cost due to ease in operation.
9. The problems of sludge bulking or sludge rising in activated sludge process and clogging in case of trickling filter are totoally absent in RBC.
10. The quantity of sludge produced is much less as compared to conventional treatment processes.

Functional Aspects

A rotating biological contactor serves three primary functions as given below:

1. It provides a large supporting surface for the growth of biomass.
2. It provides a mechanism for aeration which can be controlled by varying the speed of rotation.
3. It maintains a continuous contact between the biomass and wastewater, the intensity of which can again be

controlled by varying the rotational speed. Due to structural and drive control limitations, the RBC is normally constructed as modular unit. The number of modules depends on characteristics of the wastwater and the degree of treatment to be achieved and it varies from minimum of 2 to 6 stages

The type of material of the discs is another important consideration in RBC. Different materials for the discs have been used by various workers such as plastics, galvanized steel, stainless steel, wire mesh, aluminium and polythelene.

The geometrical parameters of RBC such as disc diameter, disc to disc spacing, number of discs, disc to tank clearance, biomass film thickness, depth of submergence of the discs and tank volume etc. have impact on the performance of the RBC. The disc diameter depends on organic load and type of wastewater. The diameter normally varies from 1.2 m to 5.9 m. Thickness of the disc varies from 10 cm to 15 cm and centre to centre spacing between the discs is kept between 20 cm and 40 cm. Generally a small clearance between the discs and the tank is provided which ranges from 0.1 cm to 1.91 cm. The submergence of discs in a tank varies from 24 per cent to 50 per cent of the disc diameter. Number of discs per stage varies from 10 to 15. In multistage units, the discs are 5 to 6 per stage.

Rotational speed usually varies from 0.75 to 15 RPM with a corresponding linear velocity ranging from 3.14 to 81.7 m/min.

The biomass slime which gets attached on the surface of the discs and which is responsible for the biodegradation has a thickness ranging from 1.60 to 5 mm. In actual field conditions, when feeding is started, it takes 2 to 6 weeks time for the slime to develop and the system to reach steady state operation.

Design Considerations

The major design parameters for the RBC are explained below:

(1) **Areal loading rate :** This is expressed as kilograms of BOD per unit area of the discs per unit time and in practice it is denoted as kgBOD/m^2/day. The organic areal loading rate depends on type and characteristics

of the wastewater and incoming BOD load. For domestic sewage its value ranges from 0.01 to 0.024 $kg/m^2/d$.

(2) **Volumentric loading rate :** Volumetric loading is the quantity of organic matter (BOD) degraded per unit volume of reactor per unit time. The parameters is significant only if a large quantity of dispersed growth organisms exists. It is expressed as kg of $BOD/m^3/d$ or $kgCOD/m^3/d$. Typical values of volumetric loading vary from 5-12 kg COD m^3/d.

(3) **Hydraulic loading rate :** Hydraulic loading rate is the volume of wastewater in m3 applied per unit surface area of the discs per unit time. It is expressed as $m^3/m^2/day$ and varies from 1 to 10 $m^3/m^2/d$. This parameter is not very significant from the efficiency point of view since it takes into account only the volume of wastewater and not the BOD or COD load. This can, however, be used as a parameter for cross-checking the design.

The maximum hydraulic loading which can be applied depends on several factors including the organic matter present in the wastewater. The influence of volumetric load on the performance of RBC depends on the active biomass concentration present. Judicious selection of loading rates is important to achieve the desired treatment efficiency.

Work done by many research workers has shown that with the attached growth systems, very high organic loading rates can be achieved and for a given percentage of COD removal efficiency, the organic loading possible is proportional to the mass of microorganisms in the system. The greater the mass of microorganisms, greater will be the potential for removal of mass COD.

(4) **Hydraulic retention time :** The hydraulic retention time control the reactor size or volume and is expressed in hours. For the RBC process, it varies from 2 to 12 hrs. However, it depends on strength of the wastewater.

(5) **Rotational speed :** The rotational speed of the shaft on which the discs are mounted is an important parameter from the process efficiency point of view, since the speed of rotation provides chance of contact of wastewater with

the biomass and oxygen. This varies from 5-10 revolutions per minute (RPM). The rotational speed controls the power consumption required to run the discs. The power consumption of RBC is the least as compared to other treatment methods as shown below :

Power Requirement for Different Treatment Processes

Process	Power Consumption Kwh/kg of Influent BOD
Extended Aeration	2 - 4
Activated Sludge	1 - 3
Aerated Lagoon	0.5 - 1
High Rate Trickling Filter	0.2 - 0.3
Low Rate Trickling Filter	0 - 0.10
RBC	0.05 - 0.10

Design Criteria under Indian Conditions

Based on the extensive studies on pilot scale as also full scale, following general design criteria for the RBC has been evolved. This can only serve as a guideline and the exact criteria need to be evolved on case to case basis.

Detention Time	-	1.5 hrs
Rotational Speed	-	5 RPM
Temperature	-	25 - 32°C
Influent BOD	-	200 - 300 mg/L
Per cent Removal	-	90 per cent
Detention Time for SST	-	2.5 hrs

Process Control Parameters

Important process control parameters of the RBC system are:
- Influent BOD concentration.
- Surface hydraulic load.
- Rotational speed.
- Effective disc surface area.
- Depth of submergence of discs.
- Liquid retention time.
- Wastewater temperature.
- Stage number

Hydraulic and Organic Loading

The importance of organic loading has been overlooked by many researchers except Stover's work. Organic loading combines both hydraulic loading and organic concentration. Hydraulic loading alone does not determine the efficiency of RBC performance because a high hydraulic load combined with low organic concentrations in the wastewater can be treated satisfactorily as long as the hydraulic detention time is longer than 50-60 minutes. Conversely, a highly concentrated waste at a very low hydraulic loading rate still requires 50-60 minutes for satisfactory treatment. Beyond the 50-60 minutes range, organic removal is insignificant. Organic loading is useful for comparison with activated sludge process or oxidation ponds. The RBC process as a fixed film biological filter is relying on the active biomass growing on the surface of discs for effective treatment of wastewaters. The influent organic loading was found to be the most important variable and had largest sensitivity value of 0.77. The same effluent BOD concentration model showed that the every 1 per cent increase in influent flow (hydraulic loading), will result only 0.165 per cent increase in effluent BOD concentration.

For rotating biological contactors, several publications clearly demonstrate that the organic load is the most important design and operational parameter. The removal rate at a given organic load was the same whether the organic load was due to high substrate concentration at low hydraulic load or low substrate concentration at high hydraulic load.

Shock Load

In a study of upgrading the trickling filter effluent for domestic sewage, it was found that the short terms hydraulic shock loading had the same effect on RBC performance as the low temperature. In contrast to low temperatures and hydraulic shock loading, organic shock loadings did not adversely affect the RBC system efficiency. For the study, the organic shock loads were 24 to 240 per cent greater than the average loadings normally received by the RBC system. The RBC system possess a very large reserve capacity to accommodate an organic shock loading associated with trickling filter effluent and upto 15.1 gm/m^2/d of soluble BOD could be handled.

Effect of Staging/Stage Number

In treating domestic wastewater, significant improvement was observed by increasing from two to four stages with no significant improvement with greater than four stages. Several factors could account for this phenomenon. The reaction kinetics would favour plug flow or multistage operation. With a variety of wastewater constituents acclimated biomass for specific constituents may develop in different stages.

While treating phenol formaldehyde wastewater the research worker used two types of RBC configurations, viz. 1 shaft 4 stage and 3 shaft 3 stage RBC. The 1 shaft 4 stage RBC unit had achieved 85 per cent phenol removal efficiency and 70 per cent COD removal efficiency. The stage 1 RBC removed 70 per cent phenol and 50 per cent COD. Stage 1 had very thick biofilm growth while the stage 3 had thin biofilm growth. Based on the results of different configuration, it was concluded that for high strength wastewaters containing 200-400 mg/L phenol and 1,500-2,000 mg/L COD, 1 shaft 4 stage and 3 shaft 3 stage RBC series at a hydraulic detention time of 4.5 hours was sufficient to remove 99.9 per cent phenol, 100 per cent formaldehyde and 91 per cent COD.

A review of literature indicates that the existing plants built in the United States possess a maximum of six stages that are commonly arranged in series. The fraction of BOD remaining in the RBC plant effluent, when initial BOD concentration is not in excess of 355 mg/L was found to be adversely affected by the stage number.

At a given mass loading of BOD_5, the treatment efficiency will increase with an increase in number of stages in series. For most municipal wastewaters there would be little practical difference between three and four or four and five stage treatment.

Hydraulic Detention Time

Marsh has stated that at low flows (long retention times), the rate of substrate removal will be controlled by the substrate organic loading rate while at high flow (short retention times) the rate of substrate removal will be controlled by the hydraulic loading rate. In order to attain complete substrate removal, the RBC system must be operated in the substrate limiting range at a removal rate less than maximum.

Temperature

Banerji in his state-of-the-art summary paper compiled data which indicated that temperature effects on RBC performance increased, not decreased with decreasing temperature.

Cheung while studying the effect of temperature used ambient temperature rather than the liquid temperature due to the reason that 67 per cent of the time the bacteria on the rotating disc were subjected to air temperature and 33 per cent of the time they were submerged in the wastewater. This showed that for RBC, the effect of ambient temperature should be investigated instead of water temperature. The temperature coefficient in his study were between 1.004 and 1.023 for the ambient temperature range of 15-32°C. Since these values were small, he concluded that the effect of temperature on the RBC performance under tropical conditions in Taiwan could be neglected. The relationship between temperature coefficient (ϕ) and BOD loading showed that at higher organic loading the effect of temperature on the removal efficiency tends to become greater. This implied that organic load was more important design parameter than temperature.

Disc Rotational Speed

Khan and Raman reported the lab scale RBC unit performance at different rotational speeds of 3,5 and 8 rpm for domestic sewage treatment. The overall BOD reduction at 3, 5 and 8 rpm obtained were 83, 88 and 89 per cent. Increasing the speed beyond 5 rpm, there was marginal increase in the BOD removal efficiency for the same organic loading rate.

Previous investigations have shown that RBC treatment efficiency can be a function of rotational speed. Weng and Molof found that for a single 15 cm diameter (6 inch) disc RBC system, nitrification was enhanced with the increased rotational speed in the 10.5 - 42 rpm range. Bintanja presented experimental data that can be arranged to show that the oxygen transfer efficiency for a set of clean 0.6 m diameter discs rotated through a range of 7.5 to 35 rpm with 29 per cent of the area submerged can be described by the equation ($\ln KL = a \ln W + b$). KL is oxygen transfer coefficient and W is the rotational speed.

The rotational speed of the media is an important factor because it serves as an aeration and mixing device. Performance of RBC is improved when speed is increased but the improvement is apparent upto a limiting speed and thereafter it is marginal. For RBC system treating domestic wastewater, it has been found that the limiting speed occurs when the peripheral velocity of the disc is approximately 0.30 m/sec.

Energy Requirements

Estimates of energy requirements of 0.006 hp/m^2 (0.56 hp/ 1,000 sft) are based on the manufacturer's data and an assumption of 70 per cent efficiency for the motor and reduction gear combined. From the manufacturer's data, the energy requirement based on kg of BOD removed is calculated to be equivalent to 0.052 hp/ kg of BOD removed. In comparison, the energy requirement of an aeration tank activated sludge is approximately 0.076 hp per kg of BOD removed. This shows that RBC requires much less energy of about 69 per cent of that required for the activated sludge process.

The power requirement for rotation of the RBC shaft is dependent upon the rotational speed. Investigators have determined that the power requirements increase as the square of cube of the speed of RBC shaft. Power requirement by way of actual measurements have been reported to be 1.9 to 3.5 kilowatts per 100,000 square feet of media surface area. These values are based on rotational speed of 1.6 and 1.7 rpm.

Because of the fact that oxygen transfer increases as the 1/ 2 power and energy increases as the square, the single stage system has a low power requirement over the multistage system. Since many plants have variable organic loading which will change from month to month or year to year, it is necessary to provide design flexibility in rotational speed such that power optimization can be made at all times.

Power requirements for the RBC system have been reported by several workers. Typical power requirements for obtaining the stated efficiency of BOD removal is given below:

Wastewater	% BOD removal	Kwh/kg BOD removed
Fresh Sewage	50 - 90	0.0163 - 0.0815
Fresh Sewage	90	0.0326 - 0.1305
Septic Sewage	90	0.1631 - 0.2936

Disc Material and Diameter

The selection of suitable material for the discs in RBC system is one of the important factors. Research workers have reported different materials of discs. Desirable properties of the material have been the low density, rigid shape and sturdyness. Disc material such as expanded polysterene, asbestos, aluminium, plastics, plexi glass, polyethelene, glavanised steel, bamboo mat, masonite and in Japan, high density polysterene, hardened polyvinyl chloride (PVC) and fiberglass reinforced plastic (FRP) has been used.

The depth of submergence used by the investigators lie in the range of 40 to 55 per cent. However, some investigators have used depth of submergence as low as 33 per cent to as high as 88 per cent.

The number of stages used by the investigators ranged from minimum 1 to maximum of 36 with a normal value of 4-5 stages and the number of discs per stage varied from 4 to 25.

The disc rotational speed varied widely starting from a minimum of 1 rpm to as high as 18.5 rpm. However, the normal speed range tried by most of the workers is between 4-12 rpm.

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6

Domestic and Municipal Wastewater Treatment : Biological Options

Introduction

The domestic and municipal wastewater was treated by convention sewage treatment plants having a number of step-wise treatment facilities. This facility is usually helpful in removing total suspended solid (TSS), BOD (Biochemical Oxygen demands), COD (Chemical Oxygen demand), and also nutrients like phosphate, nitrate etc. However, conventional systems require considerable energy input. As such low cost biological treatment facilities which emerges as a potent alternative method for wastewater treatment appears to be more popular day-by-day. In addition, persistent toxic environmental contaminants such as pesticides, aromatic hydrocarbons and metals were also removed from wastewater through biological treatment processes. In recent years, effective treatment is achieved by the construction or management of wetland so that enviromental conditions favour rapid degradation and cleaning of effluent. (Reddy and DeBush, 1987; Reddy and Smith, 1987) In the early 1960s NASA began actively researching into the use of aquatic plant system for the treatment of wastewater. Interest was initially centred on the use of aquatic macrophytes namely *Elchhornia crassipes* based treatment system. The system has now been in successful operation for well over a decade. Subsequently more efficient reed bed system was used as an effective substrate-plant microbial filter. (Wolverton, 1987) At present over two dozens of countries have active research programmes evaluating the use of their own macrophytes in water pollution control.

Although the macrophytes based root zone method can be very effective, reductions of total suspended solid (TSS), BOB, total-

N and Total-P, yet its long-term application in a waste treatment system appears to have a number of problems viz., surface run-off of effluent, development of preferential drainage routes and poor penetrations of the soil by wastewater. With careful design, placement of inlet and outlet channels and choice of planting substrate these problems may be minimised. (Reddy and Smith, 1987: Brix 1987; Techbanoglous, 1987). On the whole, artificial wetland systems have been seen as an ecomoically attractive, energy efficient way of providing high standards of wastewater treatment. In developing countries, they have the additional advantage of representing a "low technology" solution to the treatment of sewage product by both large and small dispersed populations. Unfortunately the performance of many of these systems has not lived early expectations perhaps due to faulty design and operation of waste-treatment system of this kind.

Aquatic Macrophytes Treatment System (AMATS)

Regarding of the type of aquatic macrophytes based treatment system, whether a natural wetland or an artificially constructed wetland system with a monoculture or polyculture using either floating or emergent plants, the processes thought to operate are essentially the same. In addition to the direct uptake and accumulation of contaminants, pollutant removal may be achieved by a complex range of chemical and physical reactions, occurring at the water-sediment, root-sediment and plant water interfaces. (Good and Patrick, 1987; Richerdson and Davis, 1987)

Aquatic macrophytes, particularly floating species or reeds are capable of very high rates of growth and such growth rates are associated with high levels of nutrient uptake and demand, particularly for nitrogen and phosphorus. In order to maximize removal of nitrogen and phosphorus via direct uptake, frequent harvesting may be required to remove accumulated nutrients, encourage new growth and prevent releases from senescent plant material. In addition, direct uptake and accumulation by plants can also significantly reduce the concentration of other contaminants of wastewater viz., metals (e.g., Cu, Zu, Pb, Hg. Ni, Cr, Cd etc.), partly as a result of both active and passive plant uptake and accumulation. (Klenimann and Girts, 1987: Cooper and Findlater, 1991) Decomposing bacteria associated with plant surfaces will also utilize organic carbon present in wastewater as an energy source.

This process helps in rapid reduction of 800 of wastewater pathogenic viruses and bacteria present in sewage effluent are removed chiefly by adsorption, Pathogenic viruses and bacteria which are present in sewage effluent are also removed by adsorption onto soil particles followed by antimicrobial action of the soil root microflora. (Reddy and Smith, 1987; May et al., 1991)

Although the basic biological processes responsible for the removal of pollutants by AMATS are well established, there has been little standardization of their design or methods of construction. On the whole based largely on the root zone concept, a body of general design criteria and principles for construction of reed bed systems is beginning to emerge. (Wood, 1991) The important factors that determines the efficiency and pollutat removal potentialities of this system include the following:

- Choice of plant species;
- Substrate;
- Area of reed bed/macrophytes bed;
- The nature, loading and distribution of effluent.

Macrophytes are required to fulfil four major functions in order to be used in AMATS:

1. Filter solids out of suspension;
2. Provide surfaces for bacterial growth;
3. Translocate oxygen into the root zone, thereby increasing the efficiency of bacterial degradation or transformation of pollutants;
4. Maintaining the hydraulic permeability of the substrat.

The choice of substrata for this system is very critical. In addition to gravel, river sands and pulverized fuel ash, a wide range of soils have been used with varying degrees of success. The substrata must provide a suitable medium for successful plant growth, and allow even infiltration and movement of wastewater.

The area of reed bed or macrophyte bed be computed by the following formula :

$$A_h = KQ_d\ (\text{In}C_d - \text{In}C_1).$$

where Ah = estimated area of reed bed/macrophyte bed required;

K = constrant (5.2)

Q_d = the average flow rate of wastewater ($m^3d^{1)}$

C_0 = the average BOD_5 of the influent (mgl^{-1})
C_1 = the average BOD_5 of the effluent (mgl^{-1})

Although AMATS have been used to treat screened primary sewage effluent, their long-term efficiency is improved if the effluent is pretreated by storage in a settlement tank or pond for 24 hrs. at least prior to discharge into the active macrophyte bed or into the treatment lagoon. During storage of sewage effluent, the BOD may be reduced by 30 - 40 per cent as suspended particles settle. The removal of part of the suspended solids will help to prevent the treatment system from prematurely silting up.

The major difference between conventional methods of wastewater treatment and AMATS is that in conventional systems wastewater is treated rapidly in a highly managed and energy intensive way, whereas AMATS rely on a slow flow of effluent through the system giving long retention times. Thus, the discharge and flow of wastewater through AMATS must be regulated so that retention times are sufficiently long for pollutant removal to be efficient.

Microbial Processes for Wastewater Treatment (MPFWWT)

The use of microbes in treatment of wastewater can be divided into two general categories. The first are engineered system with broadly similar process designed to those used for non-living sorbents, i.e., column contractors and immobilized cells. The commonest processes using viable microorganisms for toxic substance removal from liquid wastes are the biological treatment systems of sewage treatment plants. Activated sludge and trickling filters both possess complex microbial communities efficient at removal of toxicant from liquid. The second category encompasses the use of living complex communities, consisting of microbial, algal and plant biocatlysts together with associated animal communities in aquatic and wetland habitats. These can be either naturally occurring or man made artificial enclosures or impoundments.

Considerable literature has been documented in recent years about the application potentialities of use of microbes in toxicant like metals, pesticide transformation for waste-water (Bumpus et al., 1993; Kennedy et al., 1990) The microbial bioremediation process primarily involves five major stages viz., bioaccumulation of pollutants from wastewater system, harvesting of microbes leads to removal of contaminants, restocking of fresh microbes for subsequent accumulation and removal of contaminant from wastewater; treatment of contaminated biomass either for recovery or reuse for some purposes. The basic bio-remediation flow process is shown in Fig 1.

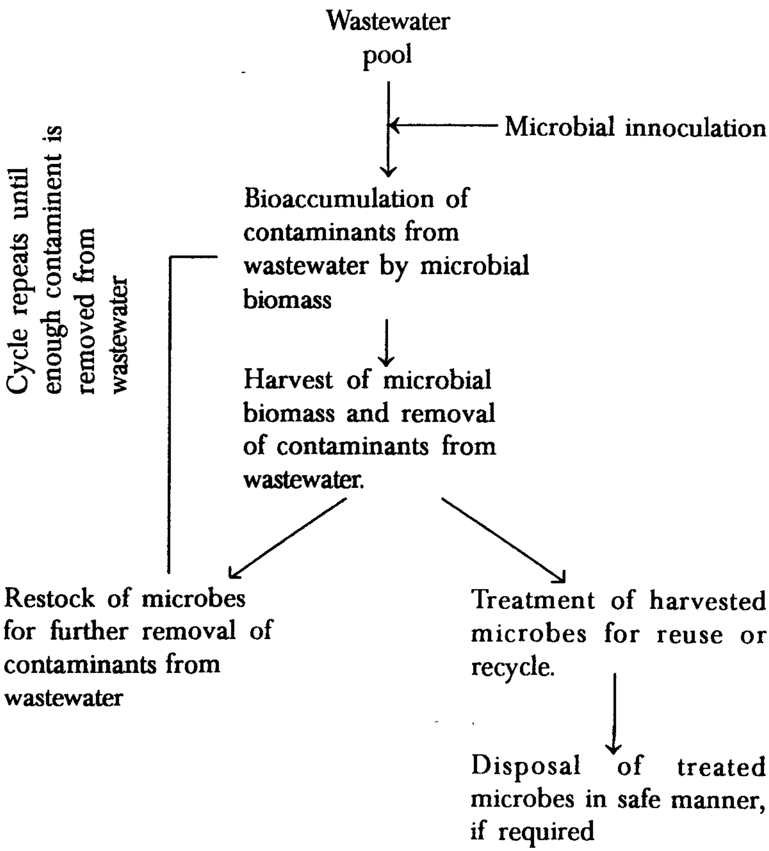


Fig.1. Basic microbial bioremediation process (modified after Vernon et al., 1995)

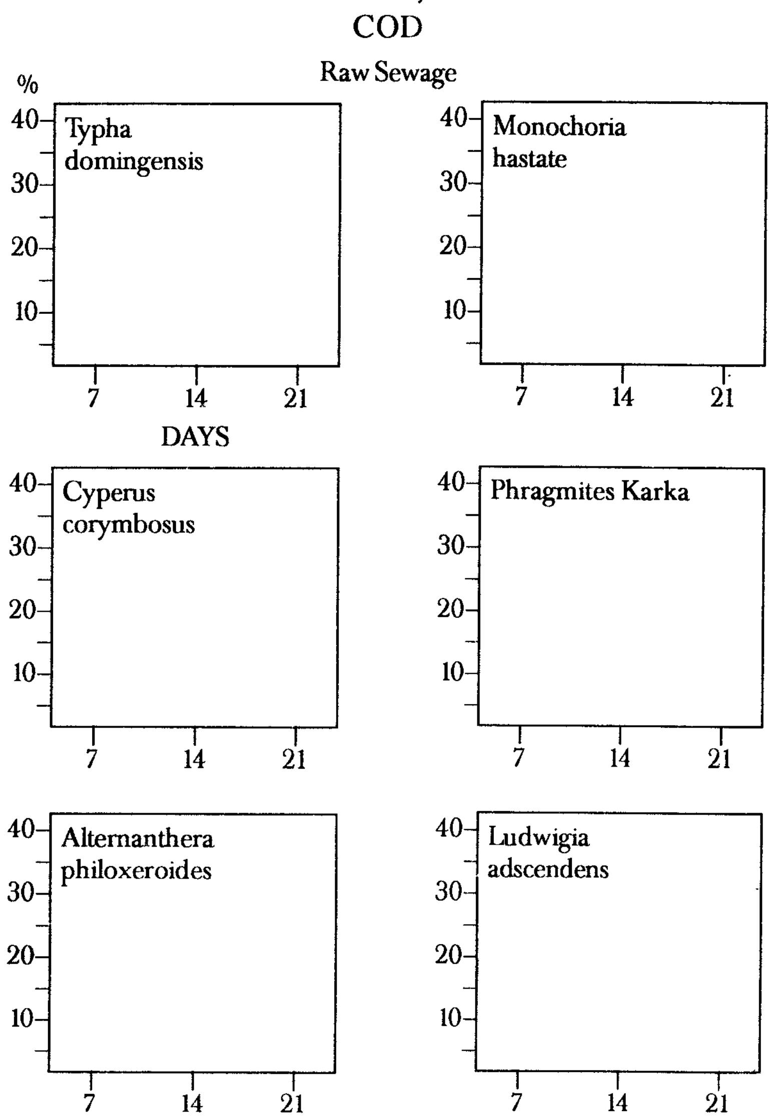
Municipal Wastewater Treatment by Tropical Aquatic Macrophytes : A Case Study

Several aquatic macropytes are morphologically and physiologically well adapted for absorption of nutrients from wastewater. Among them the most important macrophytes were ***Eichhornia crassipes, Lemna minor, Lemna gibba, Spirodela polyrhiza,***

S.punctate, Azolla filiculoides, Najas flexilis, Egeria dense, Potamogeton crispus, Scirpus lacustris and ***Phragmites australis.*** Over past three decades several studies were made by using different macrohpytes in municipal and domestic waste water treatment. (Steward 1970; Anon,1971; Haller et al, 1971; Rao et al. 1973; Dunigan et al. 1975; Fekete et al. 1976; Wooden and Dodd, 1976; Ozimek,1978; Wolverton and McDonald, 1979; Davis, 1980 Stowell et al, 1981; Reddy et al, 1982; Straves and Knens, 1985; Reddy and Smith ,1987; Armstrong and Armstrong, 1988; Brix and Schierup, 1989 and Kitoh et al.,1993). In India, a good number of aquatic macrophytes were reported to grow in polluted waters. (Davis and Ray,1966; Chaphekar at al.,1973; Singha and Bhargava, 1984; Gopal and Chamanial, 1991 and Ghosh et al.,1993). The potentiel uses of these aquatic macrophytes in waste-water treatment systems are many-folds. In addition, this is a low cost method and very simple designed; treament system as can easily be constructed for wastewater treatment.

Generally domestic and municipal wasterwater are characterised by high total dissolved slides (TDS), Biochemical Oxygen demand (BOD), chemical oxygen demand (COD), nitrate nitrogen and phosphate contents. These pullutant load can easily be reduced to a great extent by growing a number of aquatic macrophytes in artificial tank. In a study made by Ghosh and Santra (1994), it was reported that severel macrophytes have differential ability for removal of pollutants. Twelve macrophytes were tested for their cleaning efficiencies using raw and treated wastewater.The plant's efficiency for removal of COD from raw wastewater can be arranged in the sequence as *Phragmities, Typha, Monochoria, Cyperus, Alternaria* and *Ludwigiasp.* However performance of these plants with respect to removel of nitrate nitrogen is satisfactory. ***Alternanthera philoxeroides*** and ***Typha domingansis*** proved to be better than other species in all respects. In case of primary treated wastewater, *Salvinia* provided better option than others in almost all respect followed by **Lemna** sp. Plants like species of ***Typha*** and ***Nymphoides*** were proved to be better than all other plants tested for wastewater treatment following secondary treatment. The best performed cleaning efficiency of different plants using different types of waste water are depicted in Fig. 2, 3, 4 and 5. The pollutant removal rate is very much time dependent and the relative rates and are widely differing.

Considering all these facts a model macrophytes based wastewater treatment facilities were also suggested (Fig.6). Thus, the use of tropical aquatic macrophytes in the field of wastewater treatment is very much promising and intuitively correct approach towards reducing pollution levels from wastewater and gaining wealth for economic benefit of the society.



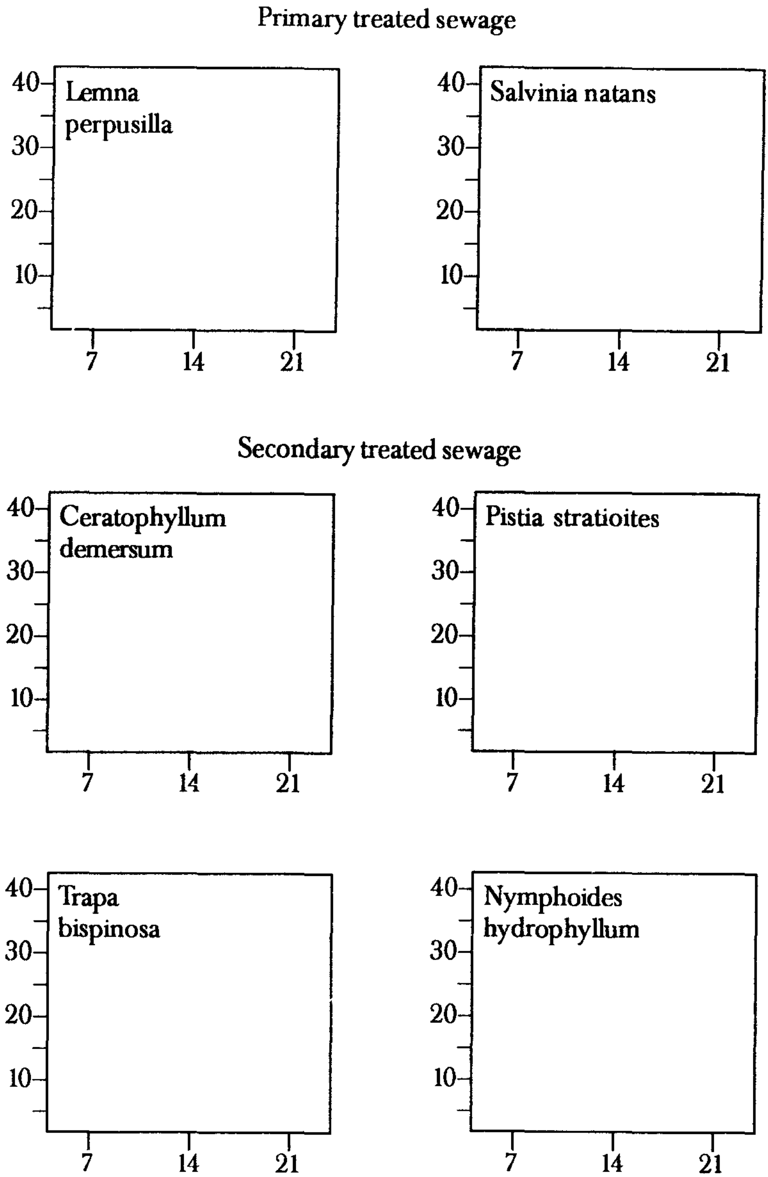
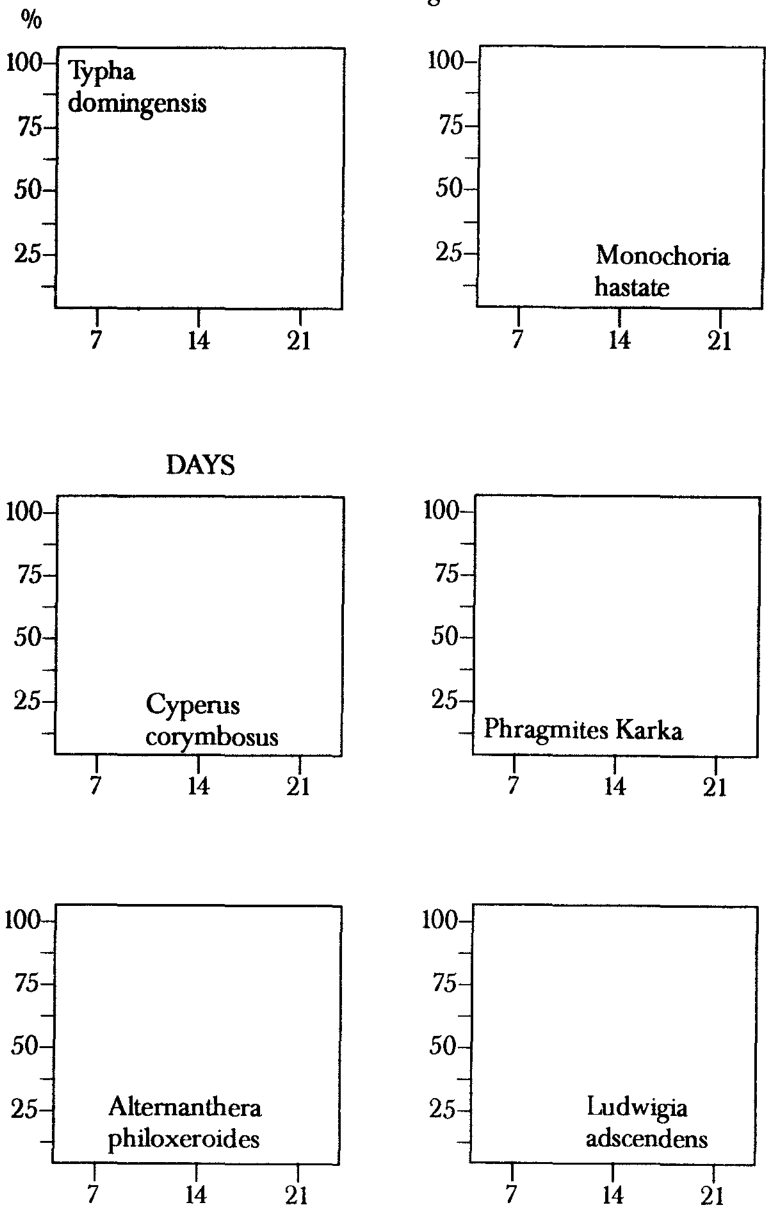


Fig. 2 : Cleaning efficiencyof acquatic macrophytes in different types of municipal waste water

NO_2–N

Raw Sewage



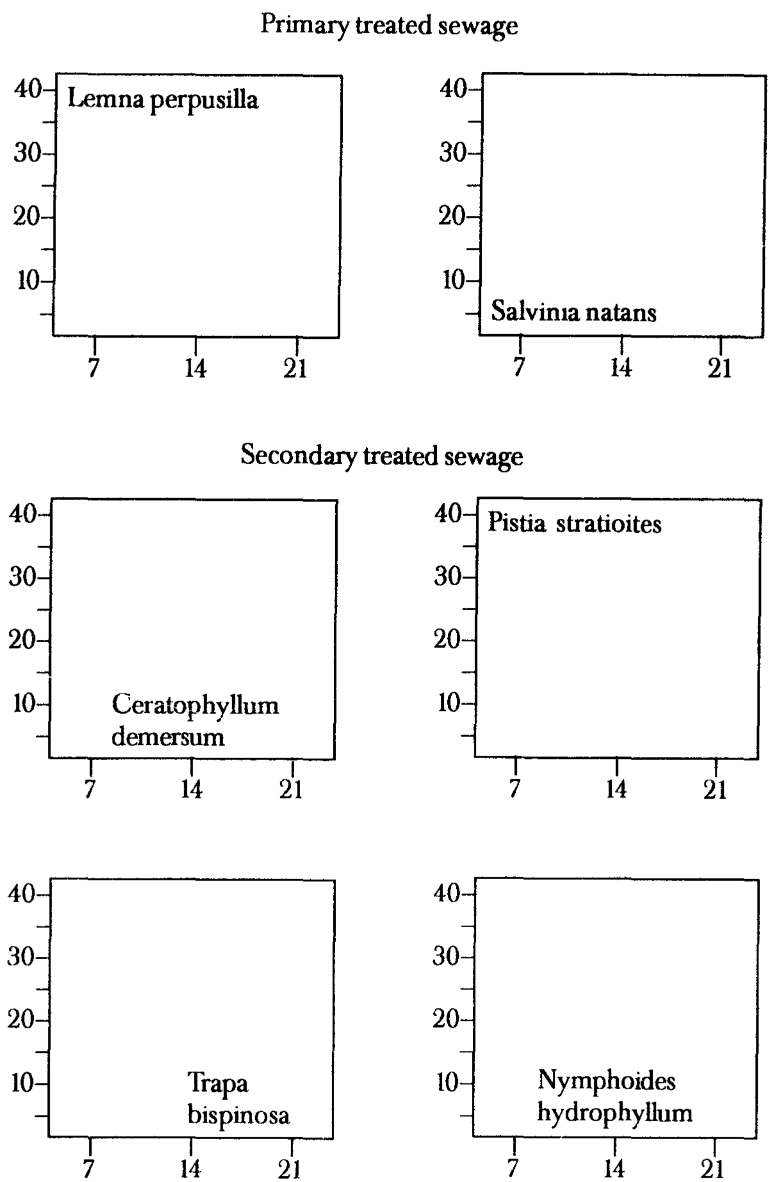
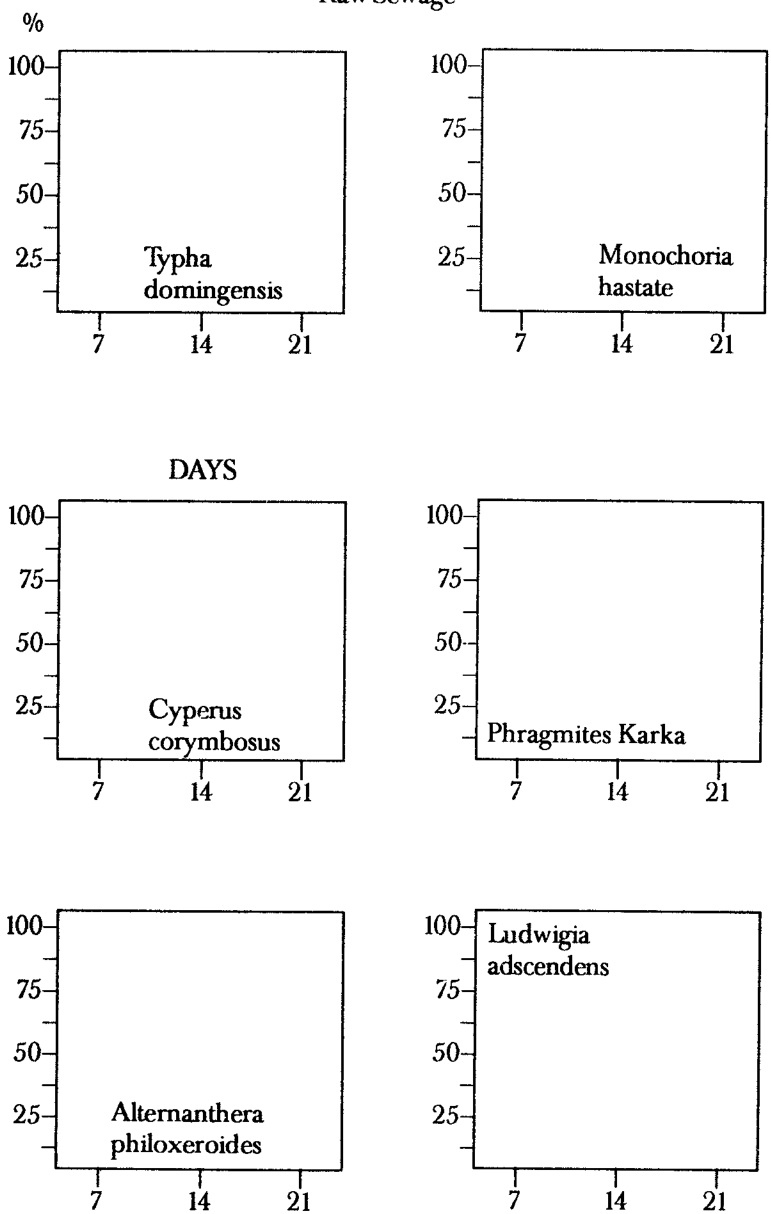


Fig. 3 : Cleaning efficiencyof acquatic macrophytes in different types of municipal waste water

TOTAL-P

Raw Sewage



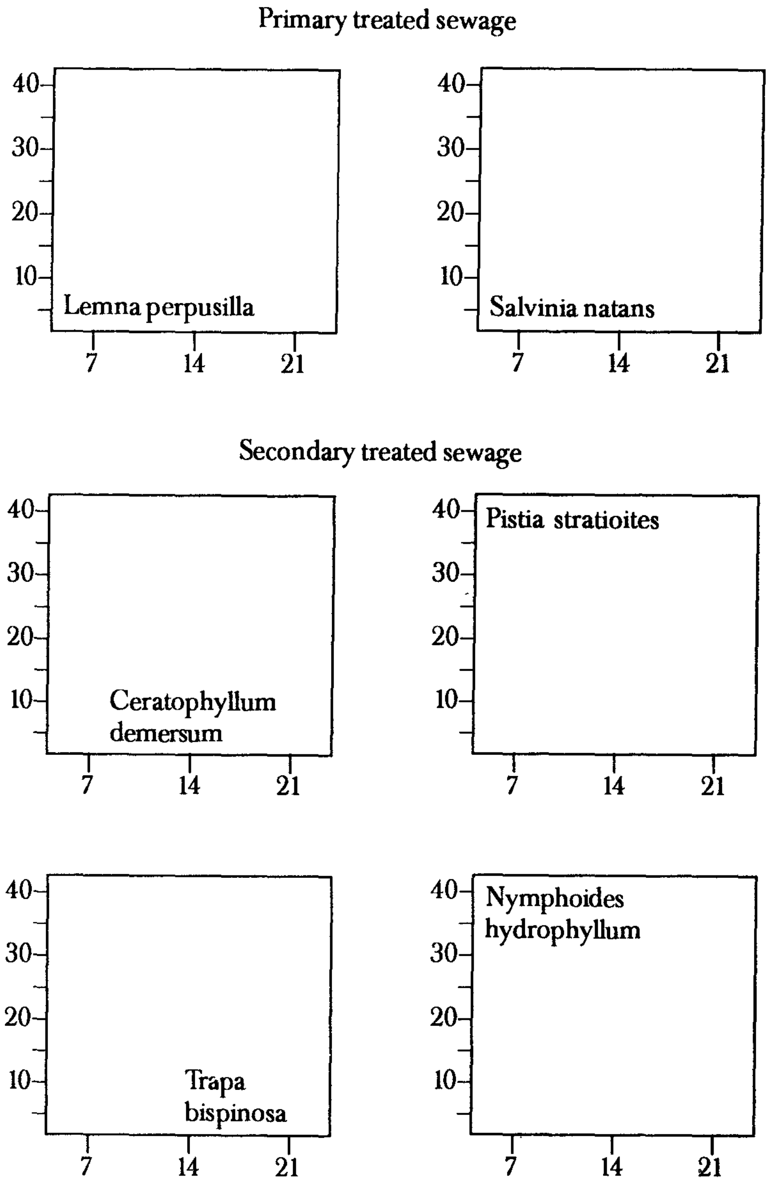
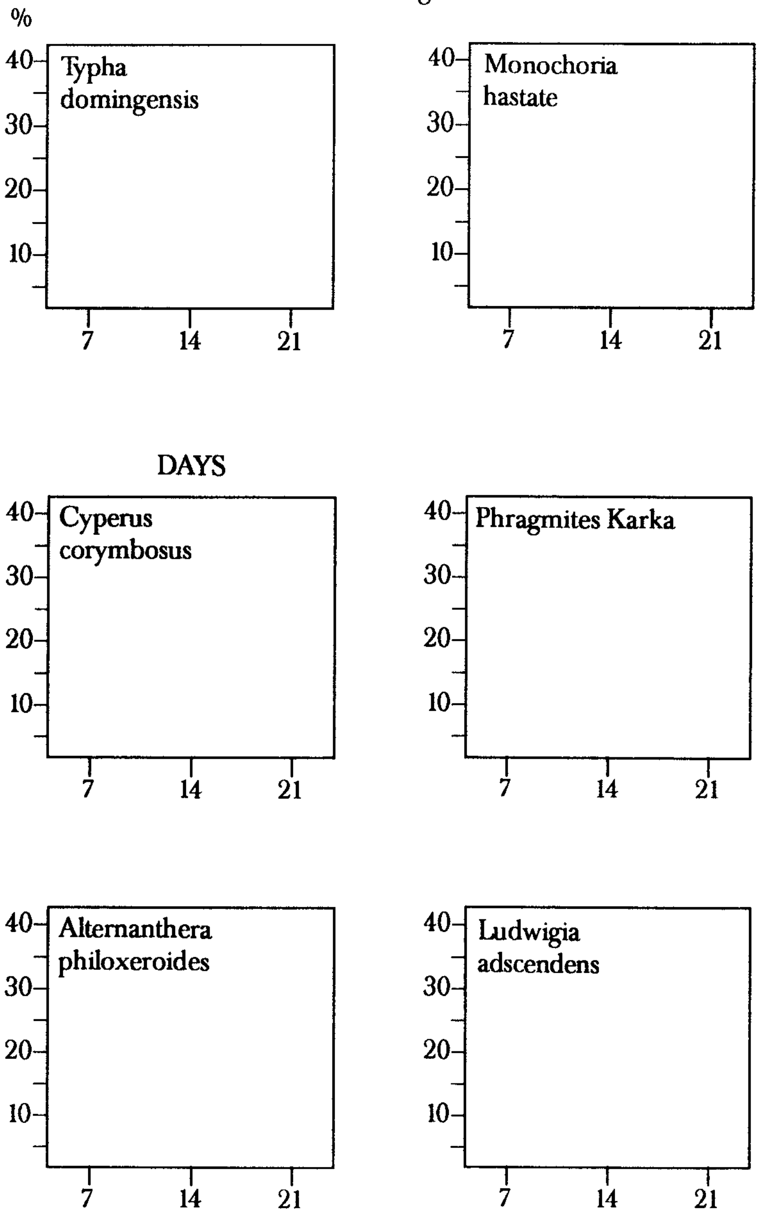


Fig. 4 : Cleaning efficiencyof acquatic macrophytes in different types of municipal waste water

BOD

Raw Sewage



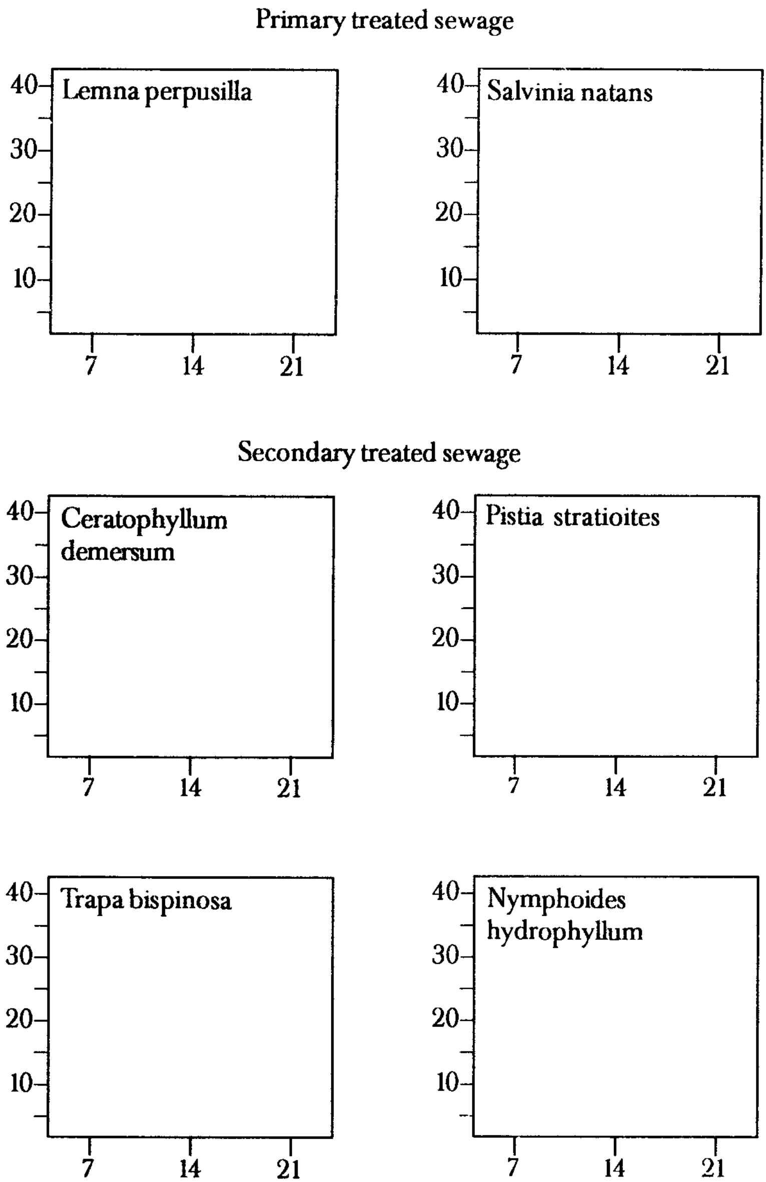


Fig. 6 : Cleaning efficiencyof acquatic macrophytes in different types of municipal waste water

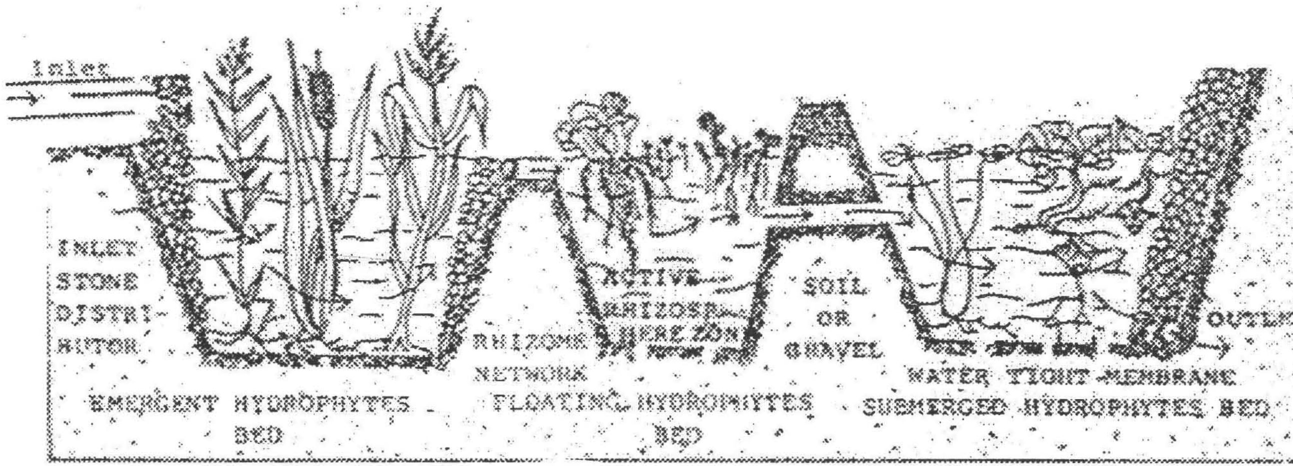


Fig. 6. Composite wastewater treatment system. Consists of emergent floating and submerged hydrophytes. Treatment concept mainly based on the efficiency of three types of hydrophytes. Usually the lagoons are not sealed except emergent hydrophytes bed.

SUMMARY

The uncontrolled dumping, land application and accidental spills of toxic environmental pollutants pose a continued world-wide environmental threat, in particular to aquatic environment. Bioaccumulative contaminants are rapidly absorbed out of water borne ambient environments, and concentrated in the tissues of living aquatic organisms at concentrations that can range from thousands to millions of times greater than levels in the ambient environment. These absorbed levels are high enough to cause dysfunction in the organisms and potential harmful effects to humans. Various bioremediation processes, thus, could be used in next millennium to filter, concentrate and remove bioaccumulative contaminants from polluted aquatic systems.

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7
Macrophytic Metal Uptake and Enzyme Bioassay

Introduction

'Biomonitoring' is considered to be an alternate effective quality assessment procedure for water pollution level diagnosis by the use of biotic community. Macrophytes are considered as an important materials for such biomonitoring purpose. Earlier the qualitative distributional pattern was used as a marker for assessment of water quality (Caffrey, 1987; Reddy and Smith, 1987), Gopal and Chamanlal, 1991, but currently enzymatic markers ae used as an efficient tools for water quality assessment. (Castillo et al., 1987; Roy and Hanninen, 1990, 1992; Debnath, 1996)

There were numerous reports in the literatures indicating the changes in enzyme activity associated with pollutant fumigation experiments. The first enzyme polyphenol oxidase which was used as an indicator of pollutant stress, showed remarkable precision on the assessment of pollutant induced damage on plant. Subsequently the peroxidas bioassay was also used as a good indicator of pollutant stress. (Curtis and Howell, 1971; Mudd, 1973; Hallgren, 1978; Debnath, 1996) Substantial enhancement of these anzyme activity was reported after exposure to air pollutants like SO_2, NO_X, HF, O_3, HC or exposure to dissolved water pollutants like metals, pesticides and other complex organic substances.

Aquatic macrophytes are most productive in wastewater. They have the ability to assimilate nutrients such as nitrate, phosphates and metals. They also create favourable conditions for decomposition of organic matter by their microbial associates. This ability can be exploited in the restoration process of natural and waste-water systems. The selection of appropriate macrophytes for treatment process is highly essential for effective field application.

Metal Uptake By Aquatic Macrophytes

Various kinds of polluted aquatic habitats were densely vegetated by aquatic macrophytes. They have fairly high potential for pollutant sink or transformation. Among the pollutants metals were mostly absorbed by the plants and stored in different plant parts. The efficiency of metal removal by different plants depends on pattern of uptake by individual plant and also their tolerance to each metal toxicity. (Hutchinson and Czyrkka, 1975; Mungur et al., 1997; Hazra, 1998). In a recent *in vitro* experimental trial using three commonly occurring floating macrophytes viz., *Pistia stratiotes, Lemna minor* and *Azolla pinnata,* it was noticed that uptake of different metals are concentration dependent and also decreased with time (Table-1).

Enzyme Bioassay

Biochemical monitoring using enzymes appears to be one of the very sensitive techniques of pollution biomonitoring in aquatic environment. In general, the activity of degradative enzymes will be enhanced many fold when exposed to pollutants. Peroxidese (POD) bioassay techniques were performed by using a few macrophytes showed that metal pollutant load enhances the peroxidase (POD) activity (Table-2). Thus after proper standardization, the peroxidase activity can be used as a biomonitoring techniques for detection of pollutants of aquatic system. In addition the activity of this enzyme is strongly related to the pollution tolerance capabilities of individual macrophytic plants. (Roy and Hanninen, 1992)

Metal Tolerant Aquatic Macrophytic Plants

Screening of metal tolerant macrophytes are highly essential for low cost and efficient treatment of toxic industrial effluents. In the past couple of decades sewage fed fisheries became very popular as sewage contains high amount of nutrients viz., nitrate, phosphate, sulphate and carbonate etc. in addition to several metals in fairly high concentration. There is potentialities of high fish productivity in sewage fed fisheries but associated risk of accumulation of toxic metals cannot be overruled. As such there is a great need for evolving low cost techniques of metal removal from wastes. Macrophyte based toxic wastewater treatment using tolerant plant species is considered to be much more effective solution to the long standing problems. Metals sinked by the macrophytes bound

Table–I Metal uptake efficiency by selected macrophytes (Hazra, 1998)

	Plant species	Days of plants	Amounted / calculated (ppm)								
			Cu			Pb			Zn		
			A	B	C	A	B	C	A	B	C
1.	Pistia Stratiotes (root)	3	0.168 ±0.002	0.147 ±0.001	0.119 ±0.003	0.072 ±0.001	0.046 ±0.001	0.030 ±0.001	0.112 ±0.002	0.084 ±0.003	0.048 ±0.001
		6	0.132 ±0.003	0.101 ±0.001	0.072 ±0.005	0.064 ±0.003	0.038 ±0.002	0.028 ±0.001	0.102 ±0.002	0.072 ±0.001	0.056 ±0.001
		9	0.083 ±0.001	0.052 ±0.001	0.032 ±0.003	0.52 ±0.003	0.043 ±0.001	0.038 ±0.002	0.068 ±0.001	0.54 ±0.001	0.038 ±0.001
2.	Pistia Stratiotes (Shoot)	3	0.120 ±0.001	0.082 ±0.001	0.050 ±0.002	0.072 ±0.003	0.034 ±0.001	0.020 ±0.003	0.124 ±0.002	0.088 ±0.002	0.072 ±0.003
		6	0.076 ±0.001	0.060 ±0.001	0.045 ±0.003	0.700 ±0.001	0.052 ±0.001	0.040 ±0.002	0.094 ±0.001	0.082 ±0.001	0.046 ±0.001
		9	0.068 ±0.001	0.042 ±0.001	0.30 ±0.001	0.054 ±0.001	0.046 ±0.001	0.036 ±0.002	0.760 ±0.002	0.032 ±0.001	0.028 ±0.002
3.	Lemna minor (whole plant)	3	0.146 ±0.001	0.112 ±0.003	0.084 ±0.001	0.116 ±0.002	0.076 ±0.003	0.034 ±0.005	0.094 ±0.003	0.054 ±0.002	0.038 ±0.001
		6	0.114 ±0.005	0.064 ±0.001	0.044 ±0.001	0.102 ±0.001	0.080 ±0.001	0.052 ±0.002	0.080 ±0.001	0.056 ±0.002	0.050 ±0.001

Contd.........

Table-1 Contd.

		9	0.100 ±0.003	0.054 ±0.002	0.400 ±0.001	0.096 ±0.003	0.056 ±0.001	0.032 ±0.001	0.052 ±0.001	0.046 ±0.001	0.039 ±0.002
4.	Azolla filiculoides (whole plant)	3	0.156 ±0.002	0.132 ±0.001	0.105 ±0.002	0.142 ±0.001	0.106 ±0.001	0.096 ±0.001	0.106 ±0.001	0.078 ±0.002	0.056 ±0.001
		6	0.136 ±0.002	0.112 ±0.001	0.082 ±0.001	0.122 ±0.002	0.095 ±0.001	0.078 ±0.001	0.092 ±0.002	0.062 ±0.003	0.046 ±0.001
		9	0.116 ±0.002	0.098 ±0.001	0.078 ±0.002	0.106 ±0.002	0.085 ±0.002	0.052 ±0.001	0.072 ±0.001	0.056 ±0.003	0.040 ±0.002

Treatment concentration : A–1 ppm, B–0.75 ppm, C–0.5 ppm.

Table 2.
Metal stress and POD activity

Plant species	House of treat-ment	PPD activity (Units/litrs)															
		Control :	Cu					Pb					Zn				
		*Treatment concentrations															
			A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Eichhornia	48	4.57	14.71	8.77	10.30	6.25	7.63	13.31	10.72	11.76	11.11	11.20	13.31	5.47	12.50	7.58	5.48
Crassipes	72	4.57	11.11	6.34	9.47	3.82	6.63	16.71	33.33	27.78	17.34	15.15	9.24	15.63	11.76	9.79	9.94
	96	4.57	15.15	17.75	9.87	9.79	20.73	29.31	15.63	15.60	6.64	12.50	15.63	4.43	16.76	17.34	20.73
Pistia	48	12.62	12.50	16.13	17.75	15.63	14.71	8.33	10.00	18.76	9.62	5.87	10.34	5.00	6.34	6.14	5.75
Stratiotes	72	12.62	1.93	7.32	6.74	10.00	10.00	10.00	8.33	7.03	4.83	5.38	5.123	7.13	8.33	6.04	3.94
	96	12.62	5.75	6.75	7.13	5.43	8.33	4.35	7.24	4.88	4.35	4.73	5.68	6.14	4.43	3.57	8.94
Alternanthera	48	5.71	6.98	8.63	11.11	11.76	11.76	8.76	8.33	6.64	14.39	7.63	2.64	2.47	0.73	1.23	0.63
	72	5.71	7.81	5.74	6.25	6.93	10.00	5.93	9.79	10.00	11.11	16.76	1.67	4.14	1.34	2.5	1.14
	96	5.71	7.13	6.74	5.54	5.43	7.63	12.32	12.39	12.50	7.63	10.00	3.94	3.73	2.03	1.52	2.84

* Treatment concentrations : A=10 ppm, B = 20 ppm; C = 30 ppm; D = 40 ppm and E = 50 ppm.

with inorganic or organic components of cells and these are not released easily to environment even after composing of macrophyte biomass. Such composed biomass can also be used in agri-horticultural practices. These macrophytic biomass may also be used in domestic biogas production unit, where these biomass will be digested aerobically and producing there by fuel gas and nutrient rich slurry materials.

Limitations of Macrophytic Biomonitoring

Water quality biomonitoring by using macrophytes required considerable standardization of techniques. Both chemical and biological monitoring should be performed in various test systems. Plankton biomonitoring already standardized as useful techniques, such kind of standardized techniques has to be evolved in the long run. Even at a low concentration of pollutant, this biomonitoring techniques appears to be most effective. In contrary, this biomonitoring technique is helpful for screening of tolerant macrophytes which could be used for toxic wastewater treatment.

Summary

The potential use of macrophytes in biomonitoring and biogremediation of toxicant from aquatic ecosystem appears to be very significant. The use of water hyacinth (**Eichhornea crassipes**) in 1960s is the beginning of the studies in temperate climate and today many aquatic macrophytes appears to be very promising in the tropics for bioremediation purpose. A list of selected macrophytes, thus prepared for future potential use (Table-3).

Table-3

Suitable macrophytic plant species useful for waste treatment in tropics

Growth forms	Scientific names
(A) Floating macrophytes :	1. Alternanthera philoxeroides
	2. Eichhornia crassipes
	3. Pistia stratiotes
	4. Lemna minor
	5. Azolla filiculoides
	6. Salvinis natans

		7. Limnophyton obtusifolium
		8. Manchuria hastata
(B)	Submerged macrophytes :	9. Ceratophyllum demersum
		10. Ottelia alismodies
(C)	Reeds :	11. Typha domingensis
		12. Phragmitis karka
		13. Cyperus tagetiformis
		14. Sagittaria sagitifolis

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8

Biological Water Treatment using Aquatic Organisms

Introduction

The growing global awareness on the impacts of water pollution has led to greater public concern and progressive enforcement of environmental legislations. The existing water treatment methods, mainly involves chemical methods where health problems are a matter of concern. The emergence of biological systems for wastewater treatment has received growing attention since they represent an alternative cost-effective and environmentally sound approach for the removal of pollutants.

Nature has evolved a number of systems to compensate for pollution generated as a result of normal events. The functioning systems in the environment offer a variety of ways in which contaminants can be altered and transported. The best way of fighting pollution is by bio-remediation using aquatic organisms. The capacity of ecosystems that are dominated by aquatic filter-feeders and plants to assimilate inputs of nutrients and organic matter have resulted in the use of such systems to different types of waste water. The use of sewage in increasing productivity of fish culture is well known but using fishes for wastewater treatment is a recent concept. (Rajan and Paul, 1996)

In any water body, the zooplankton form an important group, consuming the detritus, algae, bacteria etc. and make themselves available to be eaten by higher organisms in the food chain, including fishes. Using filter feeding invertebrates as well as fishes to consume the organic matter in wastewater can result in decreased BOD (Biochemical oxygen demand) values and bacterial populations.

The filtering mechanisms of different filter-feeders are responsible for their efficiency in wastewater treatment. In *Paramecium*, prologations of the body called cilia sweep bacteria, diatoms etc. down the peristomial groove. The physiological structures of *Daphnia* which enable them to improve water quality are five pairs of thoracic legs which are well endowed with very fine hair-like projections. These appendages permit Daphnia to filter suspended material (algae, bacteria, protozoa, detritus etc.) and concentrate it as they move toward the mouth region. It has been found by Gellis and Clarke (1935) that *Daphnia magna* require particulate food and bacteria to reach maturity. Loeldoff (1964) evaluated the role of cladocera in a stabilisation pond system in South Africa and reported that a significant reduction in turbidity was observed at times when cladoceran populations were high. In fish, the gills bear gill lamellae and gill rakers. The gill rakers project into the pharyngeal cavity and are arranged in two to three rows. The gill rakers prevent food from escaping out through the respiratory current of water. The individual filaments of gill rakers are situated very close in filter feeders and in the case of silver carp, can remove particles as small as four microns in diameter as per Dinges (1982).

In the present study, the removal of various organic and biological pollutants from waste waters using filter feeding aquatic organisms as well as plants has been discussed. More emphasis is laid on the important water quality parameters such as biochemical oxygen demand and coliform count.

Materials and Methods

Aquatic organisms were selected based on the following criteria for wastewater treatment studies :

(a) Availability of the species.
(b) Species with filter feeding/omnivorous/detritivorous food habits.
(c) Resistance to handling and transportation.
(d) Species which can be easily cultured.

The test organisms which were selected are *Paramecium caudatum* (Protozoa), *Daphnia magna* (Daphinidae), fishes such as *Labeo rohita*

(Cyprindae), *Cirrhinus mrigala* (Cyprinidae), Channa marulius (Ophiocephalidae) and *Cyprinus carpio* (Cyprindae).

The organisms selected were cultured as per the procedures cited in APHA (1995). *Paramecium* was cultured in the hay infusion method. *Daphnia* was cultured in the manure-soil medium developed by Banta. Fish fingerlings were collected from the hatchery of Kerala State Fisheries, Kozhikode and reared in glass aquariums.

Wastewater collected from the open sewers of Kozhikode city, Kerala, was analysed for water quality parameters. The physicochemical and biological parameters studied including pH, electrical conductivity, total hardness, calcium, magnesium, nitrate nitrogen, phosphate phosphorous, sulphate, total organic carbon, dissolved oxygen, biochemical oxygen demand, total coliforms, fecal coliforms and *Eschirichia coli.*

Experiments were conducted using different test organisms. Sewage was diluted to various concentrations (5, 10, 15 and 20 ml/1). The test organisms were introduced in varying numbers/ biomass. *Paramecium* was introduced at the rate of 20 numbers/ ml, *Daphnia* was introduced in three experiment sets at the rate of 10, 20 and 30 numbers per 100ml respectively. Fishes were taken according to their biomass as 3 and 4 grams per litre. Each of these experiments had 10 replicates. Experimental sets of *Daphnia* and *Paramecium* were treated for 7 days, while the sets of fishes were treated for 15 days. The samples were analysed before and after treatment for various water quality parameters as per the methods cited in APHA, (1985).

Results and Discussion

The results of the experiments conducted indicates considerable reduction in water quality parameters. Significant reduction in biochemical oxygen demand and coliforms were observed. The test organism used, period of treatment, biomass/number, percentage reduction in biochical oxygen demand and coliforms are shown in table 1.

Table 1

Percentage reducation in Biochemical Oxygen Demand and Coliforms

Test Organism	Biomass/ No.	Period days	%Reduction In BOD	%Reduction In Coliforms
Paramecium	20/ml	7	24.07	61 53
Daphnia	30/100ml	7	54.53	98.25
Mrigal	3g/1	15	37.03	54.27
Channa	4g/1	15	32.81	98.20
Rohu	4g/1	15	24.48	92.90
Cyprinus	4g/1	15	70.00	97.00

Among the experimented invertebrates the treatment set with 30 numbers per 100 ml of *Daphnia* showed maximum percentage removal in biochemical oxygen demand and coliforms (55.43 and 98.25%) respectively. *Paramecium* at the rate of 20 numbers per ml also showed considerable reduction in biochemical oxygen demand and coliforms (24.07 and 61.53% respectively).

Among fishes *Cyprinus* showed maximum percentage reduction in BOD and coliforms (70 and 97%) respectively). *Channa* at the rate of 4 gms/1 showed percentage reduction in biochemical oxygen demand and coliforms (32.81 and 98.2%) respectively. The treatment set with *Rohu* (4 gms/1) gave a reduction in BOD of 24.48 per cent and percentage reduction in coliforms of 92.9%. In experimental sets with 4 gms/I of *Mrigal* 37.03 per cent reduction in BOD and 54.27 per cent reduction in coliforms was observed.

Percentage reduction in biochemical oxygen demand and coliforms using test organisms is shown in Figure 1

The results obtained were statistically interpreted using ANOVA (Analysis of Variance). The interpretations show that each of the treatment were significantly different with respect to biomass and rate of removal of pollutants. Maximum biomass is to be introduced into the experimental sets for optimum removal of pollutants from water. Considering biomass/number per ml as a limiting factor biological models were developed based on the above findings. The biological model evolved using the results from

PERCENTAGE REDUCTION IN BOD AND COLIFORMS

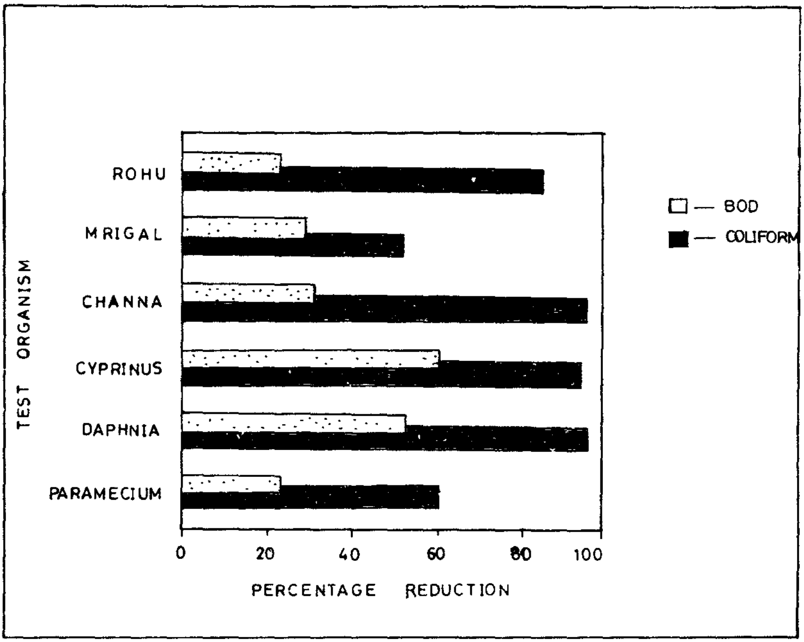

Fig. 1

experimental set of *Daphnia* is given in Figure 2. Regression equations were obtained for BOD and coliform reduction. The regression equation for percentage reduction in coliforms for a given number of organisms is

$$y = 2.2852x + 27.708$$

The regression equation for percentage reduction in biochemical oxygen demand for a given number of organisms is

$$y = 1.510x + 6.706$$

Regression model for *Daphnia* is shown in Figure 2.

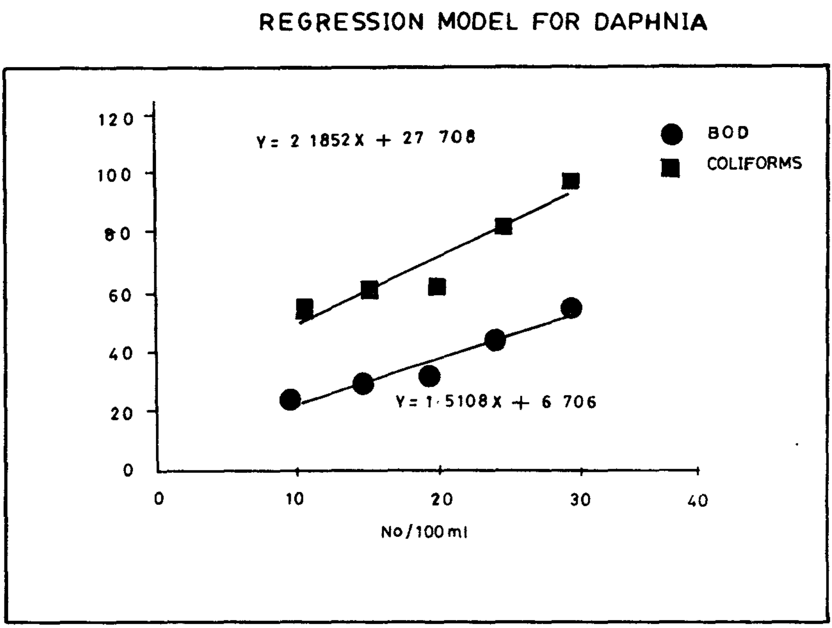

Fig. 2

Wastewater treatment via aquatic organisms is a technically feasible method for the removal of pollutants, especially biochemical oxygen demand and coliforms. Filter feeding organisms were found to be efficient in the removal of coliforms and biochemical oxygen demand. Among the experimented invertebrates, *Daphnia* showed percentage reduction in biochemical oxygen demand and coliforms of 54.53 and 98.25 per cent respectively. Among fishes, *Cyprinus* (70 and 97%) and *Channa* (32.81 and 98.2%) were found to be efficient in the reduction BOD and coliforms. The optimum biomass / number of organisms to be used for the maximum removal of pollutants has been evolved through regression modelling. The results obtained from the present study can be used to determine the number/biomass of organisms to be used for maximum percentage removal of pollutants in a large scale treatment system. The practical applications of this approach could be used for waste treatment programmes in sub-urban and rural areas which are not subject to intense competition for land use.

Acknowledgment

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9

Bioremediation of Sewage: Treatment using Immobilized *Aeromonas Sobria*

Introduction

Most of the Indian towns are not sufficiently planned to contain large population and on many occasions small towns have grown eccentrically into cities by adding up of settlements, rather than by planned development. Water is one of the major products of nature used enormously by human beings and it is not unnatural that any growing community generate enormous wastewater or sewage. As a clean environment is a prerequisite for a healthy living in any urban settlement, proper treatment and safe disposal of sewage call for prime attention of administrators. Untreated sewage can cause pollution of surface and ground waters, through which a host of diseases, both communicable and toxicity related may be spread.

Conventional sewage treatment methods employ physical, biological and chemical processes. The common physical processes are screening, comminution and removal of grit and organic suspended solids by sedimentation. Biological processes involve the agency of bacteria and algae and constitute by far the most important methods of sewage treatment, particularly in hot climates. After the removal of the suspended solids, the sewage is passed through aerated tanks (activated sludge process) or sprinkled it on deep beds of rocks (trickling filters). Chemical processes are in common use recently and considerable interest has been shown in the physico-chemical reclamation of drinking water from sewage. However, owing to the cost of the materials and the high degree of operational skill, they are unlikely to be used in developing countries, the only possible exception being the chlorination of sewage effluent.

Many new developments in the field of sewage treatment are continually taking place. These developments include improvement for more effective removal of pollutants and new treatment processes capable of removing pollutants not ordinarily removed by conventional methods. One such method with enormous potential is the use of immobilized biocatalysts.

Immobilization

Immobilization of microbial cells represents the transfer of cells from a free to a state in which they are confined or localized in a certain defined region of space with the retention of catalytic activity, so that cells can be used repeatedly or continuously. (Klein and Wagner, 1983) Use of immobilized cells have many advantages over the use of freely suspended cells. Chief among these are the capability of rousing immobilized cells and the ease with which the cells can be separated from the reaction mixture, thus preventing contamination of the product stream. Other advantages include the ability to disperse the cells evenly by immobilization so as to minimise diffusionel restrictions on the rates of reaction and the ease with which immobilized cells can be used to exploit the kinetic features of continuously stirred on packed bed reactors.

Conventional biological method of sewage treatment, both trickling filters and activated sludge, involve the use of immobilized commensal microflora a biocatalysts for the removal of carbonaceous and introgenous wastes. (Tampion and Tampion, 1987) In trickling filters bacterial cells may be bound to the surfaces of stones or man made plastics in the form of a biofilm. In activated sludge system, the cells may bind to each other through physical forces of interaction to form flocs. However, the degree of treatment in these systems vary because of the varying bacterial flora and sewage consistency, and hence the efficiency of bioremediation is difficult to be assessed.

Processes involving immobilized cells have been attempted in the treatment of effluents containing materials such as phenols (Wisecarver and Fan, 1989), paper mill sludge (Gijzen et al., 1988), distillery wastes (Subramaniyan et al.,1992), rubber press wastes

(Jayachandran et al., 1994), olive oil mill wastes (Vassilev et al., 1997) and heavy metals (Stoll and Duncan, 1997). Though the treatment of domestic sewage was attempted in India, using algae (Govindan, 1985) and cyanobacteria (Subramaniyan and Shanmugasundaram, 1986; Manoharan and Subramaniyan, 1992), the use of heterotrophic bacteria is apparently unreported for domestic wastewater. In spite of the recent interest in exploiting activated sludge for waste water treatment considering the economics involved, we have made an attempt to evaluate the efficiency of heterotrophic bacteria in the rapid treatment of municipal sewage under cell and immobilized treatment conditions, with a view to develop a more efficient technology which will pave way for less expensive technical modifications.

Study Area and Sampling

Tiruchirappalli (Trichy) municipality was selected as the study area. Tiruchirappalli is situated central Tamil Nadu (India) in between longitudes: 78.6° - 78.66° E and latitudes: 10.81°- 10.65°N on the southern banks of River Cauvery (Fig.1) covering an area of 23.26 sq. kms. It is an industrial town, with several educational institutions around. The population of the town is around 4.20 lakhs.

The Tamil Nadu Water Supply and Drainage Board (TWAD) has divided Tiruchirappalli Municipal area into six blocks for implementing the drainage scheme (TWAD, 1990). From the six blocks sewage is collected from house service connections (numbering about 22,000) through sewers of 160 km length, conveyed by gravitational force to the concerned zonal pump houses and passed through screen wells, grit wells and stored in suction wells. Further from the suction wells, sewage is pumped to the sump at the main pumping station (Fig.1) through cast iron pipes by means of non-clog centrifugal pumpsets of suitable duty installed at the respective pump houses. Sewage from Block 1 is pumped to Block 4 and then relayed to the main pumping station. Similarly sewage from Block 3 is pumped to Block 6 and from Block 2 A to 2 and all pumped to main pumping station. Sewage from Block 5 is pumped directly to the main pumping station. Entire quantity from the Main pump house is pumped to the treatment site, viz., oxidation ponds located at Panjapur.

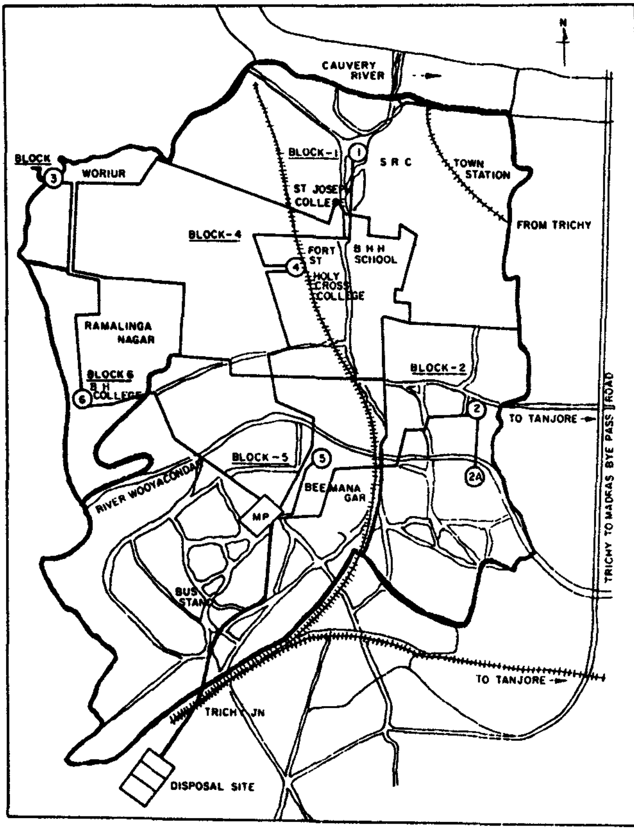

Fig. 1. Details of the Blocks and Sewage Pumping Stations

Since the entire quantity of sewage is pumped into the oxidation pond, where they are stagnated and left for natural oxidation for a few days till the ponds are full and later discharged out, it was decided to fix the stations for sewage collections one at the entry point of sewage into oxidation pond (Station 1) and another at the exit point of the pond (Station 2) from where the sewage is released out.

Sewage samples were collected from two different points for a period of one year (August 1994 to July 1995). Monthly samples for physico-chemical analyses were collected in a large container which was washed thoroughly with distilled water and dried. Samples for bacteriological analyses were aseptically collected in sterile containers and transported immediately to the laboratory and subjected to physical, chemical and biological analyses within 3 hrs. of collection.

Physical characteristics such as colour, odour, temperature and total solids (suspended and dissolved) and chemical characteristics such as pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, hardness, amounts of chlorides, phosphates, silicates, nitrogen (organic and ammonical), sodium, potassium and oil and grease were estimated following the analytical procedures outlined by APHA (1989). Protein (Lowry et al., 1951) and carbohydrates (Dubois et al., 1956) and hydrogen sulfphde (Theroux et al., 1990) contents of the sewage samples were also estimated.

Total heterotrophic bacterial population present in the freshly collected sewage samples was enumerated as colony forming units employing standard pour plate technique using plate count medium (Hi-media laboratories, India). Total coliforms and faecal coliforms associated with the sewage samples were enumerated using the multiple tube fermentation technique. (APHA, 1989) Student 't' test (Sokal and Rohlf, 1973) was employed to test whether the differences in the mean values for all the variables recorded monthly at station 1 and station 2 were significant or not?

Characteristics of Sewage

Physical: Colour of the sewage was brownish black at station 1 (entry point) and dark to bluish green at station 2 (discharge point from the oxidation pond).

Temperature : Temperature variations were in the range of 27°C-31°C at both the stations. Lower temperatures were observed in November and December, while temperature above 29°C observed between March and June.

Total solids : In the raw sewage, total solids varied from a minimum of 605 mg/l in August to a maximum of 910 mg/l in January. At the exit point of the oxidation pond the total solids were markedly lower for most of the sampling period. Suspended solids also showed a similar trend, always showing significantly lower values at the exit point of the oxidation pond (Table 1). However, total dissolved solids did not show much variation between the treated and raw sewage and the values were in the range 450-445 mg/l.

Table 1
Comparison of Various Parameters Between Station 1 & 2 Employing Student '*t*' Test

S.N.	Parameters	Station 1		Station 1		't' Value
		Mean	SD	Mean	SD	
1.	Temperatire (°C)	28.46	0.99	28.88	1.17	0.95
2.	pH	7.84	0.33	7.80	0.25	0.50
3.	Total Solids (mg/1)	859.58	28.64	637.75	21.62	21.4**
4.	Total Suspended Solids (mg/1)	357.67	29.54	124.58	9.36	26.0**
5.	Total Dissolved Solids (mg/1)	501.92	21.07	513.16	13.28	1.56
6.	Total Hardness (mg/1)	165.97	7.88	164.58	7.84	0.43
7.	Calcium (mg/1)	90.75	5.08	89.17	4.53	0.80
8.	Magnesium (mg/1)	76.83	7.90	75.42	5.62	0.50
9.	Chlorides (mg/1)	69.74	4.61	72.36	4.34	1.43
10.	Phosphate (mg/1)	12.83	1.56	18.23	1.03	10.00**
11.	Silicate (mg/1)	6.09	0.78	6.2	0.83	0.33

12.	Total Nitrogen (mg/1)	22.54	2.78	21.52	2.56	0.93
13.	Organic Nitrogen (mg/1)	6.33	0.70	6.15	0.66	0.65
14.	Ammoniacal Nitrogen (mg/1)	16.2	2.3	1537	1.93	0.96
15.	Biochemical Oxygen Demand (BOD_5)(mg/1)	171.83	13.44	162.75	9.34	1.92
16.	Chemical Oxygen Demand (COD) (mg/1)	363.5	38.77	341.75	35.26	1.44
17.	Sodium (mg/1)	31.81	4.42	32.24	4.67	0.23
18.	Potassium (mg/1)	19.28	3.02	20.67	3.05	1.12
19.	Protein (mg/ml)	0.87	0.18	0.81	0.10	1.05
20.	Carbohydrate (mg/ml)	0.26	0.05	0.20	0.03	0.93
21.	Oil & Grease (mg/l)	0.11	0.02	0.10	0.20	1.01
22.	Hydrogen Sulphide (ppm)	1.36	0.10	1.09	0.51	8.60**
23.	Total heterotrophic bacteria ($\times 10^7$ 100ml)	37.62	5.95	40.22	5.39	1.12
24.	Total Coliforms (x 10^7/100 ml)	32.05	2.61	29.65	1.95	2.67*
25.	Faecal Coliforms (x 10^4/100 ml)	20.08	1.92	18.07	1.63	2.76*

*$p<0.05$; **$p<0.001$.

pH : Sewage samples collected from both the stations recorded uniformly similar levels of pH (Range: 7.4-8.4).

Dissolved Oxygen : Dissolved oxygen was found to be absent in the raw sewage (station 1) during the entire period of collection. However, beyond the oxidation pond, the sewage had 0.5-1.0 mg/l dissolved oxygen.

Biochemical Oxygen Demand (BOD_5) : BOD_5 in sewage fluctuated sharply by recording a trough during October to January and a peak during February to April at station 1 whereas at station 2 it showed alternative troughs and peaks during the entire course of study period. In general, BOD_5 varied from a minimum of 148 mg/l in January to a maximum of 192 mg/l in April at station 1 and from a maximum of 181 mg/l in September to a minimum of 148 mg/l in April at station 2.

Chemical Oxygen Demand (COD) : Monthly variations in COD were appreciable at both the stations during the study period, and at station 1 slightly higher levels of COD were recorded than at station 2. A minimum of 310 mg/l in December and a maximum of 427 mg/l in April were recorded at station 1 whereas at station 2, it varied from a maximum of 395 mg/l in January to a minimum of 288 mg/l in April.

Total Hardness (TH) : TH of sewage sample increased steadily from a minimum of 152 mg/l during August to a maximum of 195 mg/l in November and 176 mg/l in December respectively at stations 1 and 2.

However, TH declined gradually during January to July at both the stations.

Calcium Hardness : Calcium hardness as $CaCO_3$ in the sewage showed arise during August to December and fluctuated in the latter period of study at both the stations. At station 1 it varied from a maximum of 99 mg/l in December to a minimum of 83 mg/l in May whereas in station 2 the variation was a minimum of 80 mg/l in August to a maximum of 98 mg/l in April. The fluctution observed at station 2 was irregular compared to that observed at station 1, where a declining trend was apparent.

Magnesium Hardness : Generally magnesium hardness in sewage did not show much variation between stations during the period of study, except for the month of November. Magnesium hardness varied from a minimum of 65 mg/1 in August of a maximum of98 mg/1 in November at station 1 and from a minimum of 68 mg/1 in September to a maximum of 86 mg/1 in December at station 2.

Chlorides : Chloride content of the sewage at both the stations increased sharply during August to December. Although chloride content declined steeply in January, it increased once again during February-March. Interestingly, at both the stations, minimum (62.4 mg/1 and 65.5 mg/1 for station 1 and 2 respectively) and maximum levels (78.3 mg/1 and 80.3 mg/1 for station 1 and 2 respectively) of chlorides were recorded in August and December respectively.

Phosphate : At both the stations phosphate levels increased during August to December and May to July and declined during January to April. It was observed that the mean phosphate level ws significantly ($p<0.01$) high at station 2 as compared to station 1 (Table 1). The phosphates varied from a minimum of 11.5 mg/1 in August to a maximum 16.2 mg/1 in December at station 1 and from a minimum of 17 mg/1 in August to a maximum of 20 mg/1 December at station 2.

Silicate : Silicate levels did not vary significantly between the stations during the period of study, although monthly fluctuations were prevalent. In general, higher levels of silicates were recorded during the period, November to March. They varied from 5 mg/1 in August to a maximum of 7.6 mg/1 in December at station 1 and from a maximum of 8 mg/1 in December to a maximum of 5 mg/1 in May at station 2.

Total Kjeldahl Nitrogen (TKN) : Total nitrogen recorded during the period of study showed insignificant variations between the stations. Results indicated a single peak of TKN during the month of December, when maximum levels of 28 mg/1 and 26.5 mg/1 of TKN were recorded at stations 1 and 2 respectively.

Organic Nitrogen : Organic nitrogen did not show significant variation between the stations as well as at each station during the period of study. Interestingly, organic nitrogen at both the stations showed a gradual increase during August to November and declined progressively during the later period of study. In general, the organic nitrogen varied from maximum of 7.5 mg/l in November to a minimum of 5.3 mg/l in June of 5.2mg/l in July at station 1 and from maximum at station 2.

Ammoniacal Nitrogen : There was a distinct rise in ammoniacal nitrogen initially and the steady decline during January to June at both the stations. The difference in ammonaical nitrogen between the stations were not significant and the values were almost at similar levels during the entire period of study. It varied from a maximum of 21 mg/l in December to a minimum of 13.4 mg/ 1 in June at station 1 and from a maximum of 19.3 mg/l in December to minimum of 12.5 mg/l in May at station 2.

Sodium : Sodium content of the sewage showed steep rise during October to December and declined rapidly during February at both the stations. Though sodium increased in March, it decreased gradually during the later period of study. It was also noted that the sodium content did not vary significantly between the stations, although monthly fluctuations at each station were prominent. In general, sodium varied from a minimum of 26.2 mg/l in August to a maximum of 40 mg/l in December to a minimum of 26.1 mg/l in July at station 2.

Potassium : Irrespective of the stations, there was a sharp rise in potassium during September and October and a sudden decline during the month of March. Appreciable levels of potassium was observed during December to February. Comparatively, low levels of potassium was recorded during April to July. The difference in potassium between the stations were not significant and the values varied from a nimimum of 1.6 mg/l in August to a maximum of 24 mg/l in December at station 1 and from a maximum of 25 mg/l in December and February to a minimum of 17 mg/ 1 in June at station 2.

Protein : Protein showed a distinct peak during December with maximum levels of 1.276 mg/ml and 1.01 mg/ml, and a minimum of 0.718 mg/ml and 0.719 mg/ml in June at stations 1 and 2 respectively. A sharp increase during October and a sharp decline in January and February were observed with protein at both the stations. There was no significant variation in protein between the stations, and in general, low levels of protein were recorded during March to July compared to rest of the study period.

Carbohydrates : Carbohydrates recorded an increase during October to December and a sharp decline during January and February. In general during February to July period the carbohydrates were low at both the stations, and varied from maximum of 0.321 mg/ml and 0.280 mg/ml in December to a minimum of 0.172 mg/ml in June and 0.164 mg/ml in July at stations 1 and 2 respectively. However differences in the amounts of carbohydrates were insignificant between the two stations.

Oil and Grease : Oil and Grease in sewage records distinct peak during December at both the stations, consequent to the sharp rise during the months of October-December and a rapid decline during the months of January and February. As in the case of proteins and carbohydrates, low levels of oil and grease were noted during the months of March-July at both the stations. In general, the variation between the stations were insignificant and the variation ranged from a maximum of 0.161 mg/1 and 0.139 mg/1 in December to a minimum of 0.086 mg/1 and 0.090 mg/1 in June at stations 1 and 2 respectively.

Hydrogen Sulphide : Hydrogen Sulphide content did not vary much at each station. However, there was a statistically significant decline ($P<0.01$) in the mean value at station 2 (Table 1). In general, the variation was from a minimum of 1.20 mg/1 in August to a maximum of 1.51 mg/1 in February at station 1 and from a minimum of 1.03 mg/1 in November to a maximum of 1.21 mg/1 in March at station 2.

Biological Characteristics : Among the biological characteristics total heterotrophic bacterial population (THB), Total coliforms (TC) and faecal coliforms (FC) were monitored during the course of study at both the stations.

Total Heterotrophic Bacteria (THB) : THB population did not show any significant variation between the two stations and almost similar levels of THB were recorded at both the stations throughout the period of study. THB varied from a minimum of 28 x 10^7/100 ml and 31 x 10^7/100 ml in August to a maximum of 47.1 x 10^7/100 ml and 48 x 10^7/100 ml in April for stations 1 and 2 respectively. Although fluctuations were noticed at both the stations. THB was higher (above 40 x 10^7/100 ml) in number during December to April compared to other months.

Total Coliforms (TC) : TC in the sewage samples of both the stations recorded wide fluctuations during the entire period of study. There was significant variation in TC between the stations, and station 1 recorded higher TC population compared to station 2. In general the TC population varied from a maximum of 36 x 10^5/100 ml in December to a minimum of 28.6 x 10^5/100 ml in September and May at station 1 and from a maximum of 33.5 x 10^5/100 ml in December to a minimum of 27.1 x 10^5/ 100 ml in March at station 2.

Faecal Coliform (FC) : The FC population in station 1 was significantly ($P<0.05$) higher than that of station 2 (Table 1). In general, FC population varied from a maximum of 23 x 10^4/100 ml in December and April to a minimum of 17.6 x 10^4/100 ml in May at station 1 and from a maximum of 21 x 10^4/100 ml in December to a minimum of 16 x10^4/100 ml March at station 2.

Present status of sewage treatment

Municipal sewage from Tiruchirappalli city is retained for an unspecified duration in an oxidation pond (waste stabilization pond) where the treatment processes are unaided by man, but entirely through natural processes, involving both bacteria and algae. However, in these types of ponds rate of oxidation is rather slow and long time of hydraulic retention time is needed, 30-50 days not being uncommon. Depending on the volume of sewage received into the pond, retention time vary andm thus, the rate of wastewater treatment is not desirable levels. Towns like Tiruchirappalli can treat sewage only through oxidation ponds, as the rising capital and operating cost associated with conventional wastewater treatment plants is of increasing concern to sewage authorities throughout the world. (Geary, 1988)

Physico-chemical parameters of the municipal sewage of Tiruchirappali were observed to vary according to the change of season and interestingly most of the variables showed higher levels during winter months (November to January) probably due to the concentrated nature of the sewage at that period, owing to the reduced domestic usage of water.

Among the physical parameters, temperature was found to fluctuate between 27°C and 30°C in the sewage, prior to natural treatment in the oxidation pond. Total solids varied from 820 mg/

1 to 910 mg/1 while total dissolved solids and total suspended solids (TSS) ranged from 450 mg/1 to 525 mg/1 and from 310 mg/1 to 400 mg/1 respectively. As per the data compiled by Rao and Dutta (1987) (Table 2), similar levels of these variables were recorded in the cities of Kanpur, Nagpur, Ahmedabad, Calcutta, Delhi and Chennai. Total solids reported for Calcutta were 785 mg/1, whereas suspended solids were recorded as 287 mg/1 (Calcutta), 354 mg/1 (Delhi), 530 mg/1 (Chennai), 560 mg/1 (Kanpur), 292 mg/1 (Nagpur) and 206 mg/1 (Ahmedabad). These values indicate that the quality of sewage generated in Tiruchirappalli is comparable with that of other major towns in India like Delhi, Chennai and Calcutta.

Among the chemical parameters, BOD_5 varied from 148 mg/1 to 192 mg/1 while COD fluctuated between 310 mg/1 and 427 mg/1. Dissolved oxygen was absent in the sewage prior to treatment in the oxidation ponds. BOD_5 values observed for Calcutta (125 mg/1), Delhi (203 mg/1) and Ahmedabad (186 mg/1) were all at similar levels as in Tiruchirappalli. However, BOD_5 values were at higher levels in Chennai (352 mg/1), Nagpur (334 mg/1) and Kanpur (255 mg/1). COD values were 290 mg/1 in Calcutta, 377 mg/1 in Delhi and 532 mg/1 in Kanpur. Present results are at comparable levels with the COD values for Calcutta and Delhi. The chlorides ranged from 62.4 mg/1 to 78.3 mg/1 in Tiruchirappalli. Chlorides were reported to be 147 mg/1 in Delhi, 259 mg/1 in Chennai, 114 mg/1 in Kanpur, 40 mg/1 in Nagpur and 352 mg/1 in Ahmedabad (Rao and Dutta, 1987), Raman et al., (1972) reported that the sewage of Kodungaiyur (Chennai) showed 288 mg/1 BOD_5, 402 mg/1 suspended solids, 1,060 mg/1 TDS, 205 mg/1 chlorides, 30 mg/1 ammoniacal nitrogen, 22 mg/1 phosphates and 58 mg/1 total nitrogen. Manoharan and Subramaniyan (1992) analysed the domestic sewage collected from the oxidation pond at the pumping station of Golden Rock region of Tiruchirappalli. According to this report domestic sewage of Golden Rock had the pH 7.35, 131.2 mg/1 of BOD, 90 mg/1 of COD, 2.80 mg/1 of DO, 0.30 mg/1 of nitrite, 0.003 mg/1 nitrate, 25.0 mg/1 of ammonia, 2.06 mg/1 of phosphorus, 0.48 mg/1 of organic phosphate, 1.58 mg/1 of inorganic phosphate, 34.06 mg/1 of calcium, 23.15 mg/1 of magnesium and 150.86 mg/1 of chloride. These parameters were relatively lesser for Tiruchirappalli numicipality as evidenced in Table 1, except for chloride.

Table 2

Composition of Domestic Wastewater in Different Indian Cities

Parameter	Calcutta	Delhi	Chennai	Kanpur	Nagpur	Ahmedabad
Temperature (°C)	24	–	–	27	30	30
pH	7.0	7.4	7.4	7.0	7.0	–
Total Solids (mg/l)	785	–	–	–	–	–
Suspended Solids (mg/l)	287	354	530	560	292	206
Chlorides (mg/l)	–	147	259	114	40	352
BOD_5 (mg/l)	125	203	352	255	334	186
COD (mg/l)	290	377	–	532	–	–

Ref. : *Wastewater Treatment*

M.N. Rao & A.K. Dutta, *Wastewater Treatment* Oxford IBH Publishing 1987, 2nd Edn.

A critical analysis of the differences in the various physical chemical and biological characteristics between the two stations over a period of one year revealed the impact of natural oxidation pond treatment received by the sewage before their release into the nearby uncultivated land. Among the variables, total solids (TS), total suspended solids (TSS), and H_2S were observed to have undergone reduction from their initial levels, since they were recorded at lower levels in station 2. Although the reductions were not very high, they were significant statistically (Table 1). Phosphate was observed to be high in station 2, compared to station 1, indicating enhancement on treatment. Other physico-chemical variable did not show any significant variation in their levels between the stations.

Reduction in total solids and suspended solids at stations 2 suggest the setting of suspended solids and other solids during the stagnation of sewage in the stabilization ponds. As mentioned earlier, dissolved oxygen (DO) was absent in station 1 throughout the period of study. This could be attributed to the organic load in the sewage generated by the community during various seasons, and consequently to the anoxic condition, prevailing in the raw sewage. On the other hand, station 2 recorded 0.5-1.0 mg/1 of DO which could have been contributed by the mixing of atmospheric air during the period of exposure in the pond, settling of the suspended solids and also by the meagre algal growth. The marginal decline in BOD_5 and COD–the usual indicators of sewage quality, and hydrogen sulphide do not testify to an effective treatment of sewage in the oxidation ponds. Further, the difference in Total Coliforms and Faecal Coliforms between stations, though significant statistically, does not exceed even one log number and do not thus endorse appreciable treatment through self purification.

Bioremediation of municipal sewage using *Aeromonas sobria*

As the waste stabilization pond treatment of the sewage did not affect any pronounced change, a single bacterial strain was used for the present experimental study. Among the 55 bacterial strains, primarily screened one was selected based on its efficiency to reduce maximally the BOD and COD and it was identified as *Aeromonas sobria* ATSB 238. Thus species produced amylase, proteinase, lipase and urease (Table 3) tolerated wide ranges of temperature and pH variations and withstood moderately high NaCl concentrations. They were versatile in elaborating several hydrolases, in addition to their nativity to sewage, and showed shorter generation times indicating their ability to multiply rapidly and degrade complex organic substances in the sewage. These features promoted their suitability to be used in the bioremediation of the sewage. Stock culture of this strain is maintained in the Department of Biotechnology, Cochin University of Science and Technology, Kochi.

Table 3
Characteristic Properties of *A. SOBRIA* ATSB 238

Source	**Sewage**
Colony Morphology	
Shape	Circular
Colour	White to buff
Surface	Convex, entire margin
Cell Morphology	Straight rods
Gram reaction	–
Motility	+
Biochemical characteristics	
Gas from glucose	+
Mannitol	–
Hydrolysis of urea	+
Hydrolysis of Starch	+
Hydrolysis of Casein	+
Hydrolysis of Gelatin	+
Hydrolysis of Lipid	+
Vogus – Proskauer test	+
L-arginine utilization	–
Indole production in 1% peptone water	+
Growth in nutrient broth at 37°C	+
H_2S from Cysteine	+
0/129 test (150 μg concn.)	R

+ Positive
– Negative
R Resistant

When tested the suitability of media to support growth and activity in terms of COD and BOD reductions, unsterilized sewage favoured more growth and activity compared to sterilized sewage. Perhaps, a combination of native microbial population and enhanced level of potential bacteria together could bring about maximal reductions of BOD and COD than what could be achieved individually. The native population through their activities, might compliment certain vital requirements for better performance of the added culture in the sewage.

Cultivation of *Aeromonas* on large scale

Aeromonas sobria strains selected after the proper screening were mass cultured in nutrient both for inoculation purposes. Initially 18h old agar slope culture was transferred aseptically to 10 ml of autoclaved nutrient broth and incubated for 18h at room temperature (28 ± 2°C). This culture was transferred as such to 100 ml nutrient broth and incubated on a rotary shaker (150 rpm) for a period of 18 h. Cells were harvested by centrifugation at 10,000 rpm for 30 minutes in a refrigerated centrifuge at 5°C, washed with physiological saline and suspended in 10 ml of the same saline. The concentration of the cell suspension was adjusted by reading the optical density and then used as the inoculum. This inoculum was used for mass cultivation of *A. sorbria* in sufficient quantity of nutrient broth. Cultivation was carried out in an Eyela Mini Fermenter (1.5 *l* capacity at 30°C, pH 7.0, 200 rpm mixing speed for 18 h). Cells were harvested by centrifugation (30 min, 10,000 rpm at 5°C). The harvested cells were washed and stored in 100 ml of physiological saline, maintained at 4°C in a store cool, walk in cooler (Blue Star, India), until further use.

Treatment of sewage with free cells

Initially, the optimal concentration of inoculum required for efficient treatment of sewage was determined by inoculating different concentrations of the cells (v/v) (Table 4). After incubating them for 72 hrs, the cell protein, residual BOD and COD were estimated. Influence of additional nutrients on the growth and activity of free cells in sewage was tested by the addition of 1per cent concentration each of peptone, glucose and nutrient broth. Cell protein, BOD and COD in the sewage were determined after incubation for 72

Table 4
Effect of Inoculum concentration of *Aeromonas sobria* ATSB 238 on Free Cell Treatment of Sewage (Expressed in Terms of Percentage Reduction)

Variable	Incubation period (h)	% of inoculum concentration (v/v)				
		0.5	1.0	2.0	3.0	5.0
COD	24	15.8	16.3	17.2	16.1	14.5
	48	42.4	41.9	42.6	44.2	42.4
	72	48.7	50.3	52.1	52.9	51.5
BOD	24	6.5	10.2	14.5	11.3	8.1
	48	37.1	40.9	43.0	48.9	41.7
	72	45.2	47.8	52.2	54.3	47.9

* Initial levels of COD–380 mg/L; BOD–186 mg/L

hrs (Table 5). After optimization of inoculum concentration and additional nutrients, time course sewage treatment with free cells was determined using 1,000 ml of sewage upto 72 hrs. At regular intervals of 24 hrs, samples were analysed for cell protein, COD and BOD. Percentage reduction in COD and BOD was computed considering the initial levels of COD and BOD at 0 hr as 100 per cent.

Treatment of sewage with immobilized cells :

Preparation : Whole cells of *Aeromonas sobria* grown in nutrient broth were immoblized in calcium alginate beads following get entrapment method (Cheetham and Bucke, 1984), as given below. 1.48g of sodium alginate was slowly added to 100ml of distilled water, while being continuously stirred. Stirring was continued for a period of one hour and the mixture was warmed upto 60°C to ensure complete dissolution. Under sterile conditions, 20ml of prepared cell slurry was mixed with 40 ml socium alginate solution (4% w/v) and extruded dropwise through 10 ml syringe from a height of about 10 cm into an excess of $CaCl_2$ solution. Bacteria entrapped calcium alginate beads (3 mm-diameter) were maintained in $CaCl_2$ solution for six hours for hardening. The immobilized

Table 5
Effect of Additional Nutrients on the Free Cell Treatment of Sewage by *Aeromonas sobria* ATSB 238 (Expressed in Terms of Percentage Reduction)

Variable	Incubation Period (h)	Sewage	Peptone+ Sewage	Nutrient broth +Sewage	Glucose+ Sewage
COD	24	17.6	11.0	9.5	8.0
	48	38.4	24.3	33.0	32.0
	72	51.0	46.0	44.0	43.0
BOD	24	18.0	9.0	6.0	3.2
	48	33.0	25.4	22.7	17.0
	72	50.0	46.1	44.0	40.0

* Initial levels of COD–510 mg/L; BOD–252 mg/L

cell beads were maintained in normal saline at 4°C till they were used for treatment.

Prior to the use of immobilized cell beads for sewage treatment, they were suspended in sewage for 24 hrs. period for the activation of bacteria. This immobilization procedure described here, was accepted as the ideal method, only after standardizing the factors like concentration of calcium alginate used, bacterial density level, strength of the calcium chloride solution, curing time involved, activation and retention time needed and the degree of bacterial leaching from beads, through repeated trials under varying conditions of the factors concerned.

Batch treatment process

A packed cell column reactor was prepared using a glass column (length 30 cm, dia. 4 cm) with inlet and exit valves at both ends. Prepared immobilized cell beads were slowly added into the glass column and packed at two different bed heights (5 cm and 10 cm). The void volume of the prepared bed was calculated by following the method outlined by Mohandass (1992). After activation of the bed for 12 hrs, the packed bed column was tested for its treatment of sewage. The column was filled with sewage and allowed to remain as such for treatment for a total period of 24 hrs. At regular intervals, samples were drawn and analysed for residual COD and BOD. Few beads were also removed while sampling and bacterial cell content inside the beads were estimated in terms of cell protein (Lowry et al., 1951) to determine the level of leaching of cells. Half life period of the immobilized cell beads was computed based on the performances of beads in packed bed reactor over 20 cycles of treatment. Period taken for 50 per cent reduction in the observed initial activity of the immobilized cell beads is taken as half life of the beads.

Continuous treatment

Sewage was subjected to continuous treatment by immobilized cells loaded in the packed bed column reactor. The prepared column was fed with sewage from the bottom towards the top at flow rates of 25 ml/h, 50 ml/h and 75 ml/h and using a peristaltic pump. At regular intervals of 1 hr, samples were drawn over a total period of 5 hrs, and the percentage reduction of COD and BOD were estimated.

Results of the Bioremediation Experiments

A. Sobria ATSB 238 showed maximal growth in raw municipal sewage at 30°C, pH 8.0 and at 0.3 per cent Nacl. Results presented in Tables 4 and 5 indicate that free cells of this bacterium at a 3 per cent inoculum concentration, without any additional requirement of nutrients, could bring about more than 50 per cent reduction in COD and BOD after 72 hrs. Whereas calcium alginate immobilized cells could affect reductions upto 66.3 per cent and 72.6 per cent in COD, respectively for bed heights of 5 and 10 cm and 49.5 per cent and 55.5 per cent reduction in BOD for the bed heights of 5 and 10 cm respectively, under batch process treatment in a packed bed reactor (Table 6) Half life of the immobilized packed bed reactor after running 20 cycles of batch process was recorded as 8 cycles.

It is evident from Table 7 that continuous treatment of sewage with immobilized cells is more suitable and ideal since a maximum of 53.1 per cent and 52.6 per cent of COD and BOD reductions could be observed respectively for the 20 ml/h flow rate 1 hr of treatment, although there was a marginal decline of 6 per cent in the percentage reductions of both COD and BOD after 5 hrs

Table 6
Treatment of Sewage using Immobilized Cells of *Aeromonas sobria* ATSB 238 in a Packed Bed Reactor–Batch Process (Expressed in Terms of Percentage Reduction)

Variable	Contact time (h)	Bed Heights	
		5 cm	10 cm
COD	4	20.5	35.5
	8	34.7	69.5
	12	55.0	71.6
	24	66.3	72.6
BOD	4	5.5	27.5
	8	18.7	51.1
	12	33.0	53.8
	24	49.5	55.5

* Initial levels of COD-380 mg/l; BOD-182 mg/l.

Table 7
Treatment of Sewage using Immobilized Cells of *Aeromonas continuous Sobria* ATSB 238 in a Packed Bed Reactor–(10 cm Bed Height) (Expressed in Terms of Percentage Reduction)

Variable	Time (h)	Flow rate		
		25 ml/h	50 ml/h	75ml/h
COD	1	53.1	41.9	29.6
	2	51.7	41.5	29.0
	3	50.2	40.8	28.2
	4	49.0	39.8	27.3
	5	47.0	38.3	26.1
BOD	1	52.6	42.2	29.1
	2	52.1	41.4	28.4
	3	50.0	41.4	27.8
	4	48.1	40.0	25.8
	5	45.9	38.4	23.9

* Initial levels of COD–480 mg/l; BOD–268 mg/l; Void Volume–45ml. Residence time at flow rates 25 ml/l–96 min, 50ml/l–48min, 75ml/l–32 min.

of continuous treatment. Enhanced activity in COD and BOD reductions could be observed with immobilized cells under continuous treatment compared to batch process and free cell treatment (Table 8). This increased activity might be due to the slow movement of sewage along the column which could have facilitated better contact and activity by all cells and cumulatively contributed to the total reduction in COD and BOD.

Table 8
Comparison of the Various Modes of Treatment of Sewage, Employing *Aeromonas sobria* ATSB 238

Mode of Treatment	Time (h)	Percentage reduction	
		COD	BOD
Free cell treatment	24	17.45	14.68
	48	34.12	31.35
	72	42.75	41.27
Immobilised cell treatment	4	35.53	27.48
Batch process	8	69.48	51.10
(10 cm height)	12	71.58	53.85
	24	72.64	55.50
Immobilised cell treatment	1	53.13	52.61
Continuous process	2	51.67	52.12
(10 cm bed height,	3	50.21	49.63
25 ml/hr, flow rate)	4	48.93	48.14
	5	47.08	45.90

Since *A. sobria* was isolated from sewage and adapted to conditions thereof, they could have expressed a maximal activity in short periods of activation and retention. The results clearly enunciate the potential of *A. sorbria* to express enhanced activity in continuous treatment compared to static contact of sewage in batch process, by virtue of its ability to produce several hydrolytic enzymes and tolerate the slightly alkaline condition (pH 7.4–8.4) observed with the municipal sewage. These observations further advocate the use of indigeous microbial systems for achieving efficient and rapid treatment of municipal sewage which would mimic natural conditions in the wild environment. Although there is scope for an argument that use of axenic cultures of single strains for large scale waste water treatment, particularly under immobilized conditions might not be economical, yet from the present study it is speculated that there is unlimited scope for using such potential strains along with native microcosm for enhanced activity towards rapid treatment and probable recycling of waste water for useful purposes.

Further studies using cheaper immobilization support materials like naturally available polymers or harnessing floc or biofilm forming ability of bacteria, optimization of the kinetic features and scaling up of the treatment systems, may facilitate the future transfer of this technology to the sewage management plants of the major towns of India.

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10

Need for Low Cost Effluent Treatment System in Dyeing & Bleaching Industries of Tirupur, Tamil Nadu

Tirupur–The Hosiery Town

The origin of the weaving industry at Tirupur dates back a century, with most of the firms beginning with humble pit looms. Owing to ideal climate fit for cotton processing, cheap labour and sufficient availability of raw cotton, hosiery industries in Tirupur achieved spectacular growth. Availability of container depot, share trading house, cargo facility and government subsidies for export, stimulated the entrepreneurs to start new industries here. Nevertheless technological advancement in Tirupur industrial units is not proportionate to the export potential of their products. It is interesting to note that many units which atarted as cottage industries still continue to remain so.

Tirupur has a population of about 4.5 lakh persons. About 3,000 industrial units are engaged in hosiery and knit-wear sector employing more than 1,00,000 persons directly or indirectly. The major activities in the industrial units are weaving, knitting, ginning spinning, bleaching,dyeing, printing and allied works. According to Tirupur Exporters Association (TEA), Tirupur contributes up to 85 per cent of hosiery and knit-wear produced in India and exported to European countries and the USA. During 1993-94 exports from Tirupur was about Rs. 2,200 crores. With the liberalization policy of the Indian industry and signing of GATT, TEA expects a rise in exports many folds by the year 2000.

Tirupur enterprises–currently environmentally unfriendly

On the other side Tirupur has very little infrastructure in terms of common facilities. The problems faced by the public are scarcity of potable water, drainage system, effluent treatment plant, ground water contamination and uncontrolled traffic growth. At present water requirement for various industries is being met from many open wells in and around Tirupur. River Noyyal flowing across Tirupur has been functioning as a discharge canal for the industrial effluent and municipal sewage. From industries alone the river receives approximately 75,000 M^3 of untreated effluents. To this date there are not enough facilities in operation in Tirupur to treat the effluents to the satisfaction of statutory standards. Reports on health hazards, ground water pollution, effect on aquatic life and agriculture are also common.

The river Noyyal,which originates in the Vellingiri hills of the Western Ghats in Coimbatore district, passes through Perur, Coimbatore city, Sulur, Rasipalyam, Tirupur town and Palyamkottai and join the river Amaravathi which ultimately join the river Cauvery.The flow in the river is highly reduced for the 28 anicuts, 28 tanks and 20 channels upstream of Tirupur in Coimbatore district. Downstream of Tirupur,the river is bunded at Oratthupalayam check dam which was constructed at a cost of Rs. 17 crores in 1992. The dam, located about 20 km away from Tirupur town, was conceived to facilitate irrigation of 16,000 acres of land. However, currently the dam has become an irony of developmental programmes, which are implemented without consideration of the ground reality. The farmers decline to use the water for irrigation because of heavy pollutant load from dyeing industries. Moreover, the impoundment, a repository of pollutants, is a permanent source and reason for polluting the groundwater in its environs.

Impact of Dyeing and Bleaching Industries

According to Tamil Nadu Pollution Control Board, there are around 750 industries wholly engaged in dyeing and bleaching sector in Tirupur. Most of these are functioning under small scale industry status and are in unorganized sector. Water is a primary requirement in the manufacturing process in these industries. A number of other chemicals such as wetting agents, soda ash, caustic soda, hydrogen peroxide, sodium hypochlorite, common salt, acids, dye stuffs, electrolyte, fixing agents and finishing agents are also used

(Senthilnathan and Azeez, 1999). The material to be dyed, the Gray cloth/ yarn is brought to the dyeing unit and bleaching is done to remove the impurities. Bleaching is generally carried out in two ways, Hypochloride bleaching and Peroxide bleaching depending on the material. The bleached cloth subjected to dyeing. For dyeing the dyestuffs are added in concentrations ranging from 0.001 per cent to 10 per cent.

Approximately 80,000 to 1,00,000 M^3 of water is necessary per day for the process when all the units are working in full capacity. For every kilogram of yarn approximately 200 liters of water is used, The water usage in these industry is given in Table 1. The total water requirement will be around 80,000 to 1,00,000 M^3 per day. About 75-90 per cent of this water is released to River Noyyal as effluent. At present, raw water for the industrial units are being collected from various open wells situated in the outskirts of Tirupur town. The water in the immediate precincts of river Noyyal and areas where effluent is released freely the groundwater is unusable. Estimates showed that around 1,000 lorries are operating daily to supply water. Tirupur is now gearing to get water supply from Bhavani River as the ground water sources are diminishing.

Table 1

Water requirement in various processing in dyeing and bleaching in Tirupur

S.No.	Process	Water usage (L/kg of Cloth)
1.	Hand bleaching	40
2.	Peroxide bleaching	125
3.	Light shade dyeing	70
4.	Medium shade dyeing	115
5.	Dark shade dyeing	150
6.	Sulfur black dyeing	200

Dyes and Environment

Dyes of both synthetic and natural origin, are employed for imparting colour to a wide variety of materials, but their major use is in dyeing textiles. At present 99 per cent of dyes used are synthetic because they are cheaper to natural ones and are in continuous supply. In general dyes are grounds acid, azoic, basic, direct or salt, oxidation, mordant and vat dyes. World over more than 150 chemicals are in use in dyeing industries. Use of trade names makes it difficult to find out generic/chemical names and chemical formulation of the dye chemicals and to obtain correct information on their potential health and environmental hazards.

Recognizing the inherent danger in using certain dyes the Government of India notified the prohibition and restriction of use of azo based dyestuffs in the dyeing and colour processing industries. (Kumar 1992) German legislation is very strict that no articles of clothing or items which is in constant touch with human body may be put into circulation if they release harmful anions dye to use of azo dyes. The legislation came into effect in 1995 and led to the ban on the use of about 140 azo dyes which are either known or suspected to release harmful amines, are allergic, poisonous or carcinogenic. (Ganesh 1994, Kashyap 1993) These dyes should not, henceforth, be used by any suppliers for textile of leather goods. In this context investigations are on to produce economically viable and environmental friendly dyes. Few environment unfriendly chemicals used in dyeing industries is given in Table 2.

Table 2
Environment unfriendly chemical in dyeing

S. No.	Material	Dye type	Environment unfriendly chemical in dyeing
1.	Cotton	Direct	Salt, unfixed dyes
			Copper salts, cationic fixing agents
		Reactive	Salt, alkali, unfixed dyes
		vat	Alkali, oxidizing agents, reducing agents
2.	Wool	Chrome	Organic acids, heavy metal salts.
3.	Polyster	disperse	Reducing agents, organic acids, carriers.

It has been realized that the industrialization in all countries, had been at some cost to public health and environment. Once the pollutants have affected the soil and underground water, it is extremely difficult to achieve effective decontamination. In Tirupur around 95 dyes and dye intermediate chemicals are being used. Apart from dyes, the effluent contains considerable amount of common salt, synthetic detergents, caustic soda and hydrogen peroxide. These chemicals may pose serious health and environmental hazards. A number of studies have demonstrated that the water and effluents from dyeing and bleaching factories have negative effect on human beings, animals, fish, frogs and aquatic life and plants. (Rupareliaetal 1993)

River Noyyal–water pollution monitoring study

A study has been carried out the authors' group (Sivakumar and Azeez 1996, Sivakumar and Azeez 1999, Senthilnathan and Azeez 1999) on the Physico chemical characteristics of the water of river Noyyal and effluent from dyeing factories in Tirupur during 1996-97. The water samples and raw effluents from dyeing industries were collected processed and analyzed for various physics-chemical properties as per standard method (Fresenius et al, 1987) and the results are summarized in the Table 3. The results indicate high level of pollution. The deep colour of the water is due to unspent dyes. The foul odor is due to the chemicals added during the bleaching process. COD in the range of 160 435 mg/1 is indicative of many organic synthetic chemicals. Hardness was upto 1,700 mg/1. Chloride in the range of 1,000-4,500 mg/1 clearly indicate high salt content which is used during the dyeing process and released without any treatment. The analysis of water from check dam at Orathupalyam also indicate high chloride content (4,500 mg/1) and total solid (5,800 mg/1). The farmers in the area do not irrigate the cropfields with this water. The Orathupalyam reservoir pose high chances of ground water contamination. The farmers of the Orathupalyam area complains that germination of seeds is reduced considerably on using the water from reservoir for irrigation.

Ground water pollution

The ground water pollution of Tirupur was studied recently. (Senthilnathan and Azeez 1999) The study was conducted in 8 location within the city limits. The total dissolved solids were found

Table 3
Composite results of analysis of water from River Noyyal at Tirupur

Parameters	Sampling stations				
	Kallar pallam	Karuvam Palyam	Kasipalyam	Orathupalya m check dam	Dye effluent (Direct)
Color	Gray	Red	Gray	Colourless	Dark Red
Odor	Foul	Foul	Foul	Foul	Foul
pH	8	7.6	9	8.5	8.7
Total Solids	3,490	1,770	3,700	5,840	55,170
Total suspended solids	1,240	300	500	1,900	25,970
Alkalinity	570	630	560	420	
Total hardness	1,470	1,350	1,700	1,650	
Magnesium Hardness	570	600	780	780	
Calcium Hardness	900	750	920	870	
Chloride	1,680	1,120	2,150	4,500	30,000
Sulfate	260	300	360	280	
BOD	110	120	120	110	160
COD	160	240	435	240	2,800

Expect pH, values are in mg/lt.

in the range of 1,500 to 8,000 mg/1. The results indicate that the area comes under very high salinity zone and the water is unfit for irrigation and other uses. Chloride, an index of surface pollution levels was found high in many wells ranging from 200-3, 545 mg/l, probably dye to percolation of effluents with high common salt.The high salt concentration in ground water leads to formation of saline soil and is a serious hindrance to agriculture. The concentration of heavy metals such as Copper, Zinc, Chromium, Cadmium were also analyzed. Among the metals Zinc was found highest (8.92 +0.15 to 44.04+0.199 ug/l) and Cadmium the lowest. The study concludes that most of the ground water sources are highly polluted to an extent that they are not suitable for drinking and irrigation purpose as per ISI standard. It is apparent that this is mainly due to the discharge of untreated effluents from dyeing and bleaching industries.

Effluent treatment

In order to treat the effluents from dyeing and bleaching industries major steps have been taken in recent years. Few industrial units have installed own individual treatment plants. A large number of units have formed joint companies to establish common effluent plants (CETP). For the purpose of establishing CETPs. Tirupur town and its outskirts were grouped into ten zones. Ten public limited companies were floated for the purpose and the responsibility of these companies is to closely monitor, assess and manage waste water to comply with the statutory obligations of Tamil Nadu pollution control board. At present, there are about 8 CETPs nearing completion with the technical guidance of indian Institute of Technology and Anna University, Chennai. As much as Rs. 30 crores has been spent on the CETPs and another Rs.30 crores on the individual ETPs.

The CETP set-up is an expensive project. The installation cost is exorbitant and the efficacy of the plant in terms of reducing certain parameters such as total dissolved solids from the effluent is doubtful. As an example the "Cinnakarai Common Effluent Treatment Plant" which was formed jointly by 31 individual units is taken to highlight the cost involved.The capacity of the plant is about 5000 M^3/day. This is one of the smaller unit among 8 CETPs in Tirupur. The treatment process in the CETP involve physical and chemical treatment, sand filtration, biological treatment, activated carbon adsortion and chemical oxidation. The CETP comprise of equalization tank, flash mixer, clarifocculator, collection pump, auto sand filter, static mixer, stabilization tank, chemical dosing system and sludge de-watering system. It is expected that the treatment will bring down the effluent characterislies to following levels; pH 7-8, Total Suspended Solids 100 mg/1, BOD 30 mg/1 and COD 250 mg/1.

The projected cost of Cinnakarai CETP is about Rs. 2.4 crores, the details of which are given in Table 4. Once the plant

Table 4
Estimate for Cinnakarai CETP, Tirupur

S.No.	Job	Cost (ins Rs.)
1.	Civil works	90,00000
2.	Mechanical equipment	80,00,000
3.	Electricals	25,00,000
4.	Piping (within plant)	500,000
5.	Instrumentation	500,000
6.	Collection System	4,000,000
	Total	2,45,00,000

is ready for operation, the maintenance cost will be about Rs. 20,000 per day. (CETP 1996) The details of the operation cost are given below Table 5.

Table 5
Operation costs of Cinnakarai CETP

Chemicals : Quantity of lime required	2500 kg/day	Rs. 3000/day
Chemicals : Mixed sulfate salts required	2500 kg/day	Rs. 5000/day
Chemicals : Sodium hypochloride	50 kg/day	Rs 2000/day
Chemicals : Poly electrolyte	5 kg/day	Rs 1000/day
Cost of electricity		Rs 7500/day
Man power	Rs 500/day	
consumbles & lubricants		Rs. 100/day

Problem of CETP

After the treatment in CETP the discharges will satisfy the Tamil Nadu Pollution Control Board standards for most of the water quality parameters, except the total dissolved solids (TDS). The TDS is mainly due to high sodium chloride added during dyeing. The treatment protocol followed in the CETP cannot remove the TDS. The procedure followed also generates high quantity of solid waste in the form of sludge. Currently no economically viable (low cost) technology to remove the TDS is available. The levels of TDS in effluent is about 4,000 mg/lt. When let out into the open land it may contaminate the land and groundwater with salination. It was estimated that from 5,000 M^3 of effluents, about 6,000 kg of sludge will be generated. In Tirupur, the large amount of solid waste from the CETPs and ETPs will pose a major problem of disposal. The major portion of the sludge are the unabsorbed/ \unfixed dyes, various chemicals used during the dyeing and bleaching process and effluent treatment. If the solid waste is not properly disposed or utilized, chances of environmental contaminations are high. Methods suitable to dispose or use the sludge has to be explored. Though enough investment and efforts have been taken, no economically viable solution for the problem is identified.

Alternatives

The possible mitigatory measures mentioned below may be explored to reduce the problem; (i) newer dyeing methods requiring lower quantity of salts, (ii) us lesser water, (iii) dye and salt in the process, (iv) recycling the water and dyebath, (v) biological method of treatment to reduce solid waste, (vi) explore modifications in the currently practiced treatment methods to reduce additions of chemicals which form sludge, and (vii) explore technology to convert the solid waste into useful product.

Eco-friendly methods

Water pollution is a concern of governments all over the world and emphasis is being given on low cost eco-friendly effluent treatment. (Cooper and Findlater 1990) Research workers are putting their efforts into finding solutions which are economically feasible, since in less developed countries conventional methods are very expensive and difficult to implement. Use of macrophytes has been proved to be an effective and cheap way of purifying waters. (Athie and Cerri 1987) The important points which has to be taken care while employing constructed wetland with macrophytes are climatic conditions, proliferation of insects, requirement of large area and requirement of relatively longer time. The use of macrophytes if employed in pollution abatement offers advantage of biomass production and also betterment of soil quality.

Constructed wetland or reed beds offer a potentially low cost, low maintenance biological and physical method for wastewater treatment. Many such systems are currently in use around the world, designed to treat domestic wastewater (Cooper, 1990) and also industrial effluents. These involved horizontal subsurface flow through inert porous medium planted with suitable aquatic plants such as *Phragmites australis.* Similar experiments for the treatment of textile industry waste using water hyacinth were also conducted in India (Trivedy and Gudekar 1987) The hyacinth was grown in 100, 50, 25 per cent concentrations of both original and settled wastewater for four days in tanks. The water hyacinth was found highly capable of removing pollutants from the original waste as compared to the settled waste. With the settled waste 4 days were needed to get a maximum reduction in conductivity, COD, BOD, TS, TDS and TSS. For the original waste, maximum reduction in conductivity, BOD, COD and TSS was noted on the third day itself. Nutrients such as nitrogen, sodium, potassium and phosphorous were also reduced to a considerable extent.

Constructed wetland have been employed in treating industrial effluent containing textile dyes. (Davies and Cottingham 1994) The trials were conducted in a horizontal flow, gravel bed reed (30m x 5m) and the textile dye wastewater was applied at a rate of 10 L/min. Interesting results were obtained, indicating the breakdown of the visible dyes. Majority of the break down of visible dyes occurred in the first one-third part of the bed. Such systems have capability to treat industrial wastewater containing a wide range of chemicals, including priority pollutants such as phenols and cresols, by processes such as absorption and bacterial breakdown, oxidation, adsorption on to the bed matrix and sedimentation.

The design of the wetland plays an important role in the efficacy of effluent treatment. (Cooper 1990, Marble 1991) Currently universally acceptable design criteria for constructed wetlands for similar purposes are non-existent or not intensively tried out to assess their performance. Approaches differ widely on the engaging wetlands and reedbeds for the purpose. However, a large number of researchers realize these systems as robust, low cost treatment units, providing a reasonably consistent level of treatment of wastewater, requiring little or no technical expertise in operation and maintenance. Others see them as a valuable tool in the final polishing process of recycling and re-use of water. (Mackney 1990)

Despite a lack of conformity and also information in design of constructed wetland for the purpose of wastewater treatment it is felt that the following points need to be kept in mind in designing the system.

1. The system may be designed to occupy comparatively smaller space.
2. The tanks may be arranged to minimize power requirement to pump the water. To as much as possible gravity flow may be used.
3. The plant species selected should be capable of growing fast under local climatic conditions.
4. The retention time shall be minimum with maximum functional efficiency.
5. Measures to control possible insect problem due to the set-up (wetland) should be made.
6. Possible recyling of the discharge from the plant has to be explored.
7. Resource generation from the plants shall be explored.

In general the design should focus on low investment and minimum maintenance cost. Such an attempt will mitigate the problems of effluent treatment on a long run in the developing countries which face serious resources crunch.

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11

Treatment of Hospital Waste and Sewage in Hyacinth Ponds

Introduction

Water pollution created by large scale disposal of waste water into various water resources is considered as one of the most serious problems being faced by us today. Explosive growth in human population; reckless use of natural resources, rapid industrialisation and urbanization has resulted into generation of huge amount of wastewater, which should be safely collected and treated. Billions of liters of wastewater is generated everyday from industries and domestic sources. Safe collection, treatment and disposal of this wastewarter requires huge capital investment as well as money for running these facilities.

The wastes range from simple, weak sewage containing organic and mineral matter to highly toxic kind containing pesticides, detergents, heavy metals and other toxic substances. In the absence of suitable technology and facilities for the treatment, they are inevitably discharged into fresh and marine waters. The effect is depletion of oxygen in ecosystem, consequent death of biota, smothering of aquatic animals and degradation in water quality for domestic, agricultural, industrial and recreational use. The ultimate victim is man who suffers in many ways by degradation of water quality. The epidemics of water borne diseases, accumulation of heavy metals in the body, loss of fisheries and aesthetic quality of water being few of them.

The problem of water pollution in India is particularly grave. According to National Enviromental Engineering Research Institute, Nagpur more than 90 per cent water in India is polluted. All the 14 major rivers of India are polluted and the situation is same with most of the urban lakes. (Trivedy, 1990, 1994) According to Tyagi (1991) there are around 7,500 industries of considerable pollutional significance in India and approximately 4,500 of them have put up effluent treatment plants. There are several tens of thousands of other industries in unorganized to small sectors which contribute significantly to pollution load but escape attention. Considerable amount of waste water is also generated as human waste or sewage. According to Chaudhary (1983) about 7006.74 mld waste is generated in class I cities in India, out of which 59 per cent is collected and 37 per cent gets any kind of treatment, while in class II cities about 1226.32 mld waste water is generated and only 15.54 per cent of which is collected and 5.44 per cent gets any kind of treatment. The situation must be more or less same today.

A large number of technologies are available for wastewater treatment today. Among the biological treatment methods, activated sludge process, anaerobic process and tricking filters are common in India. A variety of physico-chemical treatment methods like ion exchange, electrodialysis, reverse osmosis, flotation, chemical precipitation etc. are also available for different wastes. However, all of these technologies are capital intensive and most industries in small to medium sector find it expensive. Besides maximum establishment cost, these technologies need skilled manpower for regular maintenance; the expenditure on power and other materials are also substantial.

It has been emphasized time and again that the countries with easy availability of land and plenty of sunshine can think in terms of developing an appropriate technology with components from commercially available technology but relying heavily on the available raw materials to achieve pollution control at the same time to recycle the valuable materials from the wastewater.

Of late, there has been considerable interest in using aquatic plants in wastewater. The aquatic plants (commonly referred as aquatic weeds) are commonly found in lakes, rivers, pools, and water logged areas. These plants pose a number of problems in water resource utilization. (Anonymous, 1976)

Many aquatic weeds have demonstrated potential for wastewater treatment and nutrient absorption form the wastes. The aquatic weed based waste water treatment can be carried out either in the aquaculture system or in a reed-bed (Root zone technology). Although a number of aquatic weeds like *Pistia, Salvinia, Azolla, Wollfia, Spirodela,* and *Lemma* etc. have been used but water hyacinth *(Eichhornia crassipes)* stands out to be most promising among them. A native of South

America and a confirmed weed, this plant started spreading in tropics and subtropics in the beginning of this century. The plant is now a major threat to the water resources in about 15 countries in the tropical region of the world from South America, through Africa and Asia to the Pacific ocean. The plant is endowed with a tremendous proliferation capacity, it causes a number of disastrous effects on physico-chemical quality of fresh waters and causes an enormous financial losses. (Trivedy and Gudekar, 1985). In the past few decades, there have been considerable attempts to control this plant by adopting physical, chemical, mechanical and biological means but the plant has withstood them and continues to occupy more and more freshwater resources. Frustrated with his attempt on its control, Man has now started thinking in term of its utilization.

It was shown as early as 1968 that water hyacinth has capacity to remove nitrogen and phosphorus from secondary sewage treatment effluent pond. (Clock, 1968) Since then, there have been a large number of trials all over the world showing tremendous capacity of water hyacinth in removal of a variety of waste constituents such as nutrients, suspended particles, organic matter and heavy metals etc. Haque and Sharma (1980) reported that with a lagoon of 0.5 ha. containing dense growth of water hyacinth, the sewage of 1,000 people can be treated in two weeks getting a 75-90 per cent efficiency. Wolverton and McDonald (1976 a) have found water hyacinth an excellent substrate for upgrading sewage lagoons to meet advanced waste water treatment standards. In only seven days they observed a reduction of 70 per cent in total suspended solids and BOD. The water hyacinth has proved to be a sort of miracle for nitrogen and phosphorus removal from waste waters. These two constituents are critical factors for eutrophication all over the world and their removal from water is difficult and highly expensive by chemical means. Boyd (1970) has found that upto 200 kg/ha nitrogen and 320 kg/ha of phosphorus could be removed by using water hyacinth. Rogers and Davis (1972) have found that 2.5 acres of water hyacinth grown under optimum conditions can absorb average daily nitrogen and phosphorus waste produced by about 800 persons. Ten acre surface acres of water hyacinth can nearly remove phosphorus from typical domestic sewage of city of 5,000 people and one acres of water hyacinth can remove 1,349.5 kg N/year.

Other studies on this aspect are from Cornwell et al. (1971); Dinges (1978); Boyd (1974, 1976); Wolverton and McDonald (1976 a); Wolverton et al. (1975); Wolverton and McDonald (1976 b); Stack, (1972).

Water hyacinth has also shown its ability in the treatment of industrial wastes. Mehrotra and Aowal (1982) tried treatment of digested sugar factory waste with water hyacinth, Singh (1982); Aowal and Singh (1982) and Trivedy et al. (1983) worked with Dairy Wastes. Similar work on tannery waste was carried out by Trivedy et al. (1983) and Prasad et al. (1983) Trivedy and Khomane (1985) studied the removal of nutrients from distillery waste, textile mill waste and metal work waste by water hyacinth. Haider et al., (1983) have made observations with pulp and paper mills. John (1983) with rubber industry waste and Goodson and Smith (1970) with citrus wastes mixed treated municipal effluents.

Water hyacinth has also shown its capacity to accumulate heavy metals. It has been found to absorb and concentrate heavy metal such as lead, cadmium, mercury and nickel. (Wolverton and McDonald, 1978, 1975a, 1975b and O'Keeffee et at., 1984) The accumulation of heavy metals by the plants is so fascinating that its use has been suggested for metal recovery waste. (Gupta,1982) Trivedy and Joag (1989) have revieved the studies on treatment of industrial waste by using water hyacinth.

In India the researches concerned with water hyacinth based waste water treatment started very recently. There have been quite a few studies on treatment of sewage and industrial wastes and nutrient absorption from them by using water hyacinth (Rao et al., 1973; Rao, 1981; Kumar et al., 1982; Singh, 1982; Aowal and Singh, 1982; Trivedy et al., 1983; Prasad et al., 1983; Trivedy and Khomane, 1985) but the studies are still in rudimentary stage and require much more knowledge before the hyacinth utilization in wastewater can be taken up at commercial level.

Most of the studies on aquatic macrophyte related pollution control have been carried out at laboratory level in batch type of system; except for a medium level test facility which was set up at Sangli to treat 5 lac litres of waste per day by using water hyacinth and to produce biogas. (Jogalkar and Sonar, 1986) It is important that the performance of water hyacinth is studied at pilot or full scale to hasten its commercial application.

Present study has been designed to study the utilization of aquatic plants for pollution control in continuous flow system for both sewage and hospital waste. The domestic waste study has been carried out on a hospital waste treatment plant treating 200 m^3 waste per day by using water hyacinth.

The studies commenced with establishment of above treatment plant. The studies were carried out for one year on efficacy of this treatment plants in removal of various constituents like pH, Conductivity, Total dissolved solids, Total suspended solids, COD, BOD, Chloride, Sulphate, Ammonia, Total nitrogen, Total phosphorus, Inorganic phosphorus, Oil and Grease etc. The water hyacinth plants were also collected and analyzed regularly from these treatment plants for studies on uptake of various substances.

This study shall help in judging the performance of hyacinth based systems from various angles including their capacity, pollution control standards as well as cost effectiveness of the treatment. The study shall also help in finding out future prospects of these technologies in India.

Description of the Krishna Hospital Wastewater Treatment System

The wastewater generated in hospital is from various Departments which includes routine clinical, cytotoxic, infectious, pathological, pharmaceutical and radiological waste. This waste along with domestic waste water from medical college, staff quarters, hostel and cafeteria is first brought to a holding pond and from there it is pumped to water hyacinth based treatment system.

For the treatment of this kind of waste the biological waste treatment system have been chosen due to its more cost effective, low energy intensive, low risk hazards from the process operation etc. factors. The combined wastewater was treated in an Aquaculture (Aquatic) treatment system which is away from hospital area.

The treatment system comprises of 10 tanks which were constructed below ground level and were properly lined or pitched with the help of dry rubles, at all the vertical sides of each tank. The dimensions of each tank were 10.37x6.10x0.91m and each tank was interconnected with others by keeping the rate of flow of wastewater for the treatment of the waste, i.e. hydraulic retention period with help of hollow pipe having 225mm diameter in up and down position to the depth of each tank. The total length of the treatment system (i.e length of pits and coverage area by them) was about 86.59m and breadth was 12.5m. Important features of this treatment plant are given in table 1.

Water hyacinth plants which were well grown,fresh and collected from non-polluted areas were used for the treatment system. After achieving about 100 per cent coverage in all tanks the treatment of wastewater was examined.

Table 1
Salient Features of the Water Hyacinth Based Treatment Plant

	Krishna Hospital Waste Treatment Plant
Year of Establishment	1994
Type of Waste	Domestic
Flow/day	$200M^3$/Day
Area under the treatment plant	$632.57M^2$
BOD loading	385.09 KG/HA/Day
Retention time	3 Days
Discharge arrangement	Gardening
Hydraulic loading m^3/hqd.	1055.00

Table 10a
Air and Water Temperature During the Study of Krishna Hospital Waste Treatment Plant

Sr. No.	Month, Year	Temperature	
		Air	Water
1.	September'94	31.5	30.0
2.	October	34.0	31.0
3.	November	36 5	27.5
4.	December	30.5	22.5
5.	January'95	28.5	24.5
6.	February	32.5	22.5
7.	March	37.5	26.5
8.	April	38.5	27.0
9.	June	27.5	24.5
10.	July	26.5	24.0
11.	August	25.0	24.5

Table 10

Range of Physico-Chemical Characteristics of the Influent and Effluent used at Krishna Hospital Hyacinth Base Waste Treatment Plant

(From September 1994 to August 1995)

Ammeter	Influent		Effluent		Bast/least % Reduction Obtained
	Range	Average	Range	Average	
pH	6.50-8.65	7.71	7.23-8.20	7.72	--
Conductivity, S	735-14/	1060.64	410-990	741.45	54.19/9.30
Total Suspended Solids, mg/1	22-448	167.45	20-232	98.00	75.68/17.64
Total dissolved Solids mg/1	455-880	645.81	268-656	504.55	50.37/0.62
Total Solids, mg/1	540-1055	760.64	426-775	604.45	46.14/6.57
Hardness, mg/1	227-456.80	394.90	225-433	359.18	16.81/0.92
Calcium, mg/1	76.15-134.56	89.88	58.34-95.85	74.00	31.59/7.51
Magnesium, mg/1	9.01-100.21	53.78	16.95-137.18	51.03	53.48/1.75
Bio Chemical Oxygen Demand, mg/1	72-160	121.81	10.50-82.00	36.54	93.35/9.10

Chemical Oxygen Demand, mg/1	126-266.44	179.20	45.45-180.48	100.13	67.58/22.22
Sulphide, mg/1	1.27-6.79	4.03	0.43-3.96	1.06	82.03/36.44
Sulphate, mg/1	21.82-218.42	105.25	4.73-136.36	55.30	78.32/2.71
Chloride, mg/1	74.55-150.00	97.27	63.19-132.06	87.54	29.64/4.35
Ammonical Nitrogen, mg/1	11.34-26.40	19.82	7.12-18.62	13.51	44.10/25.86
Total Kjeldhal, Nitngen mg/1	25.65-81.90	47.24	15.34-52.50	27.57	64.30/27.22
Organic Dissolved Nitrogen, mg/1	7.42-69.86	27.80	1.27-43.08	14.03	88.48/35.31
Nitrates, mg/1	1.85-7.68	5.58	0.85-4.24	2.75	62.93/39.94
Total Dissolved Phosphorus, mg/1	4.65-18.39	11.41	2.10-9.95	4.56	82.81/38.89
Organic Phosphorous, mg/1	1.06-4.13	2.21	0.14-2.78	1.23	91.14/19.47
Organic Dissolved Phosphorus, mg/1	2.21-14.26	7.74	1.26-6.57	2.89	91.20/38.91
Particulate Phosphorous, mg/1	0.70-19.90	5.42	0.65-7.47	2.16	94.53/28.85
Oil Grease, mg/1	5.16-34.54	20.07	Nil-2.15	1.51	100/87.41

Results

Changes in physico-chemical prameteres in various tanks Krishna hospital waste te treatment plant (Table 1.12.3a 5 to 33)

pH

The pH of inlet water ranges from 6.50 to 8.65. The outlet water pH was always around 7.23 to 8.20. Better water hyacinth growth always coincided with high pH. Maharashtra Pollution Control Board's Statutory limit is 5.5–9.0 which was always met.

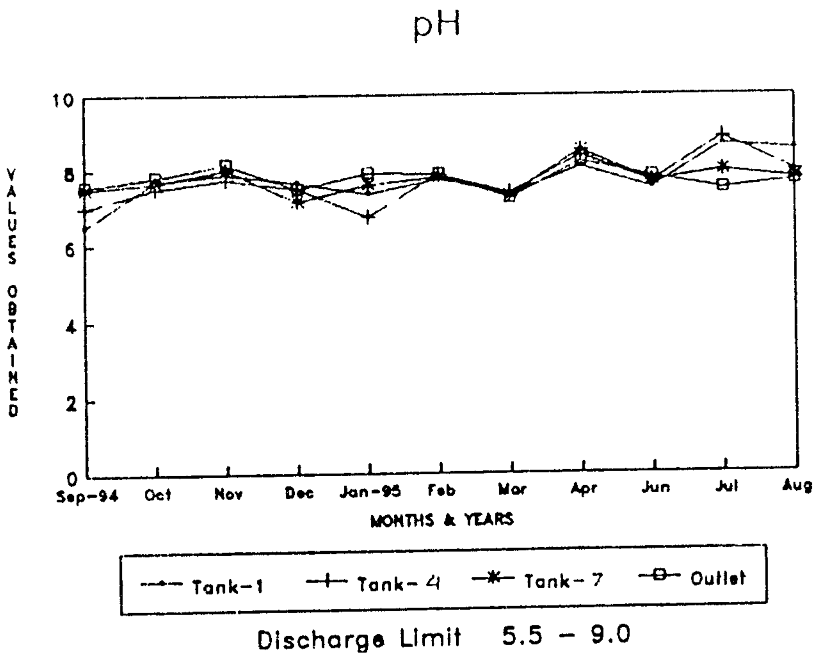


Fig. 1

Changes observed in pH during the study period at Krishna Hospital waste treatment plant in different tanks.

Conductivity

The conductivity values of inlet water ranged from 735.0 to 1480.0 µs. The conductivity decreased sharply almost on all the occasions in Tank 4 except in October 94 and January 95. The highest per cent reduction was found in November 94 (51.40%), during high water hyacinth coverage. In Tank 7 the conductivity decreased almost on all the occasions except in October 1994, but the conductivity is increased as compared to conductivity of tank 4 in November 1994. The outlet conductivity ranged from 410.0 to 990.0 µs. Percentage reduction in conductivity values in outlet in comparison to inlet ranged from 9.31 to 54.19. Maximum value was obtained in November 1994 (54.19%).

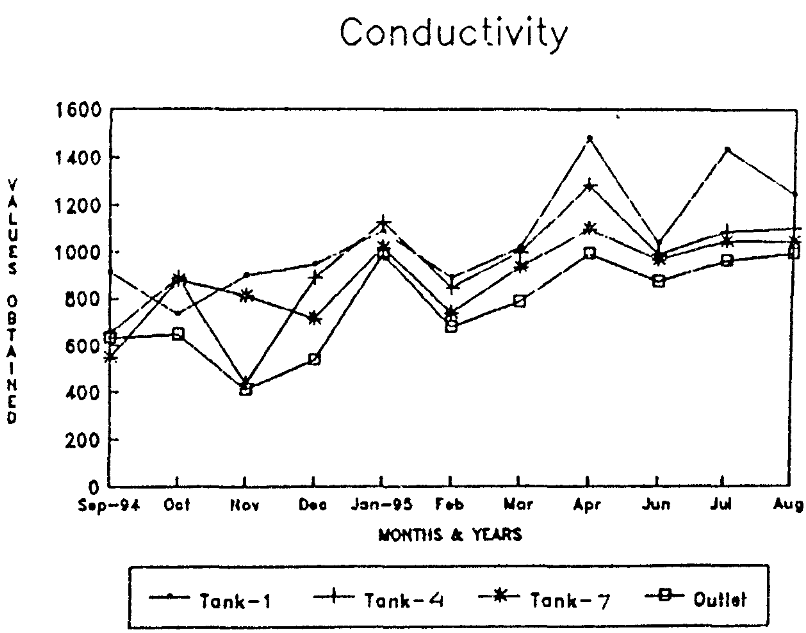
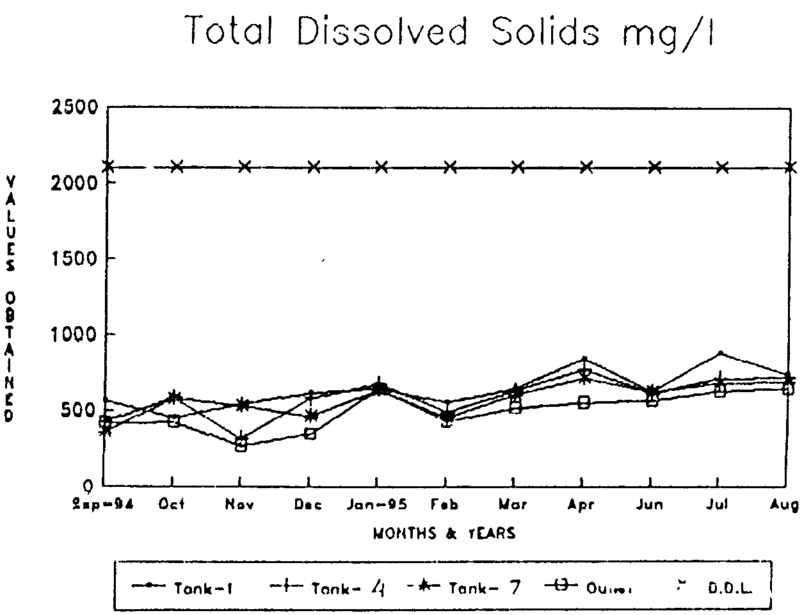


Fig. 2

Changes observed in conductivity during the study period at Krishna Hospital waste treatment plant in different tanks.

Total Dissolved Solids

The inlet values to total dissolved solids ranged from 455 to 880 mg/L. In general a decline was observed on most of the occasions except in October 1994 and January 1995. In tank 7 not much reduction was noted except in September 1994 and December 1994. The outlet concentration varied from 268 to 656 mg/L. The total dissolved solid concentration reduced on all the occasions. However only on four occasions the concentration was reduced above 25 per cent. These periods also coineided with better water hyacinth coverage. Maximum coverage of hyacinth was in the month of November 1994 and maximum reduction in total dissolved solids was also noted in this month (50.37%).



Denote Discharge Limit

Fig. 3

Changes observed in Total dissolved solid during the study period at Krishna Hospital waste treatment plant in different tanks.

Total Suspended Solies

The suspended Solids concentration of tank 1 ranged from 22 to 448 mg/L. Not much of reduction was found in tank 4 on most of the occasions except in January 95 and February 95. The total suspended solid concentration of tank 7 varied from 22 to 298 mg/L. Almost on all the occasions a sharp decline is noted except in the September 94. Maximum reduction is found in November 94. The outlet concentration ranged from 20 to 232 mg/L. In general a sharp decline was noted on thrce occasions out of eleven. The suspended solid contents usually increased in the outlet. The percent reduction in suspended solid varied from 17.14 to 75.68%.

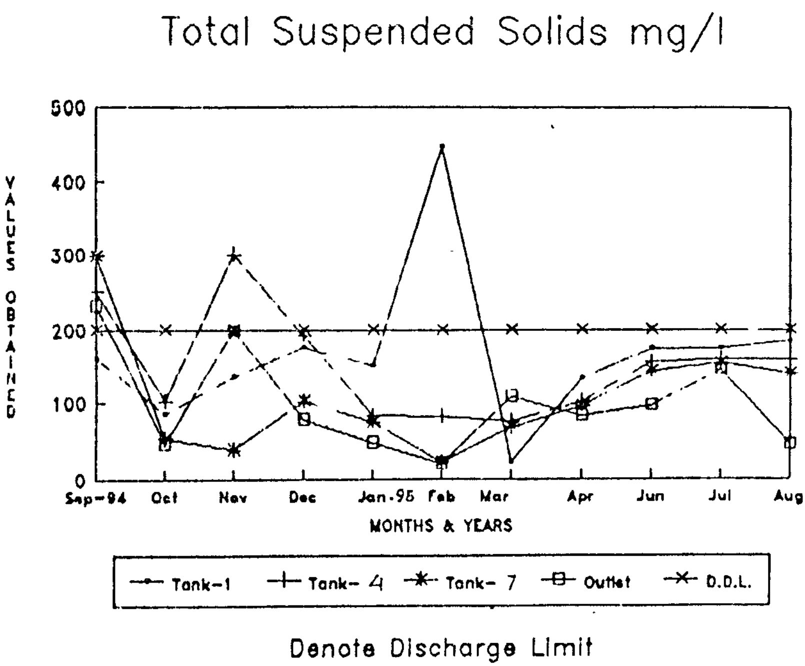


Fig. 4

Changes observed in Total suspended solids during the study period at Krishna Hospital waste treatment plant in different tanks.

Hardness

The inlet hardness varied from 227.0 to 456.8 mg/L. In tank 4 the concentration of hardness declined almost on all the occasions. Not much reduction was noted in tank 7 as compared to tank 4. The hardness concentration of outlet varied from 225 to 433 mg/L. which declined sharply on all the occasions.

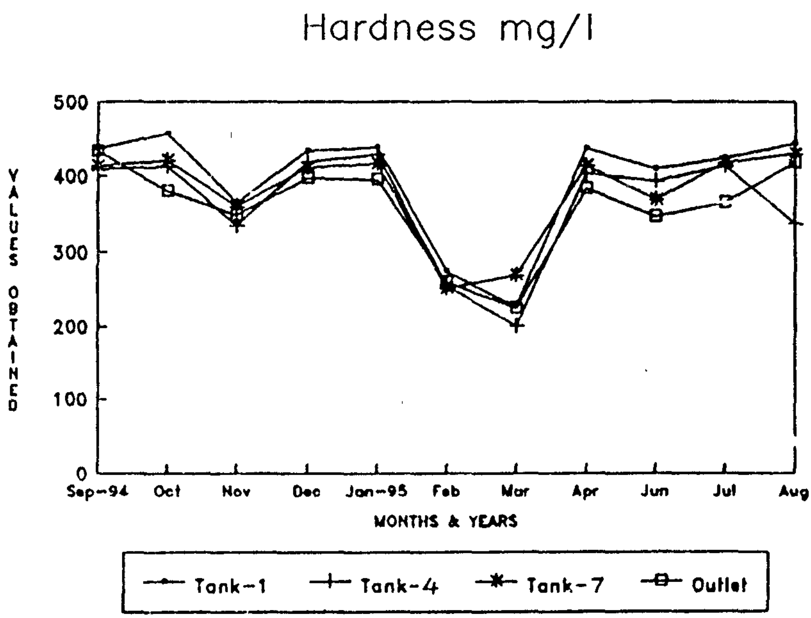


Fig. 5

Changes observed in Hardness during the study period at Krishna Hospital waste treatment plant in different tanks.

Calcium

Calcium content of tank 1 ranged from 76.15 to 134.56 mg/L. In general sharp decline was noted in tank 4 on all the occasions which coincided with the water hyacinth coverage. The concentration of calcium in tank 4 varied from 70.14 to 120.18 mg/L. Not much of reduction was observed in tank 7, in fact it increased on most of the occasions. A sharp decline was noted in the outlet almost on all the occasions. The outlet content ranged from 58.34 to 95.85 mg/L. Maximum reduction observed coincided with maximum coverage of water hyacinth.

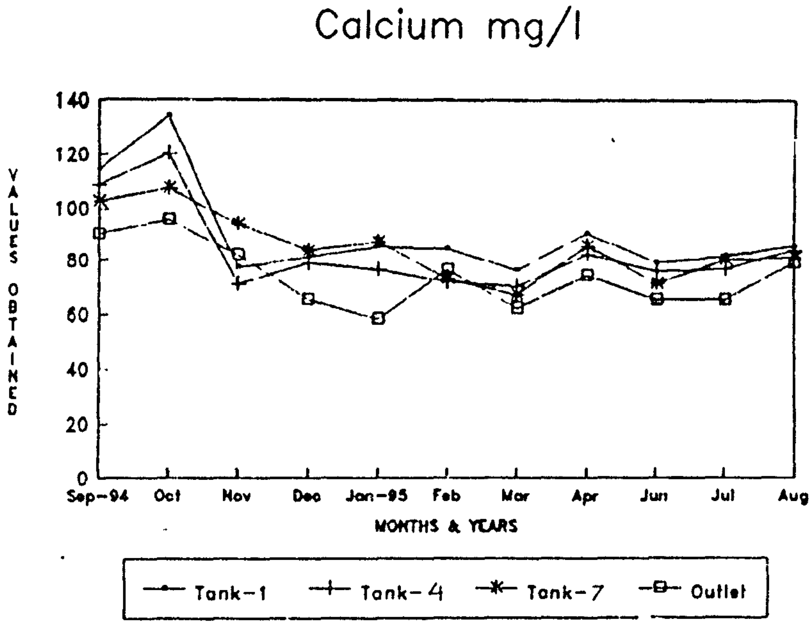


Fig. 6

Changes observed in Calcium during the study period at Krishna Hospital waste treatment plant in different tanks.

Magnesium

The magnesium content of tank 1 varied from 9.01 to 100.21 mg/L. It got reduced on almost all the occasions in tank 4. However, it increased in tank 7 on most of the occasions. No sharp decline was observed as compared to tank 1 and tank 4. The outlet concentration ranges from 16.95 to 137.18 mg/L. Maximum reduction was observed in October 1994 (53.48%). The reduction observed coincides with hyacinth coverage.

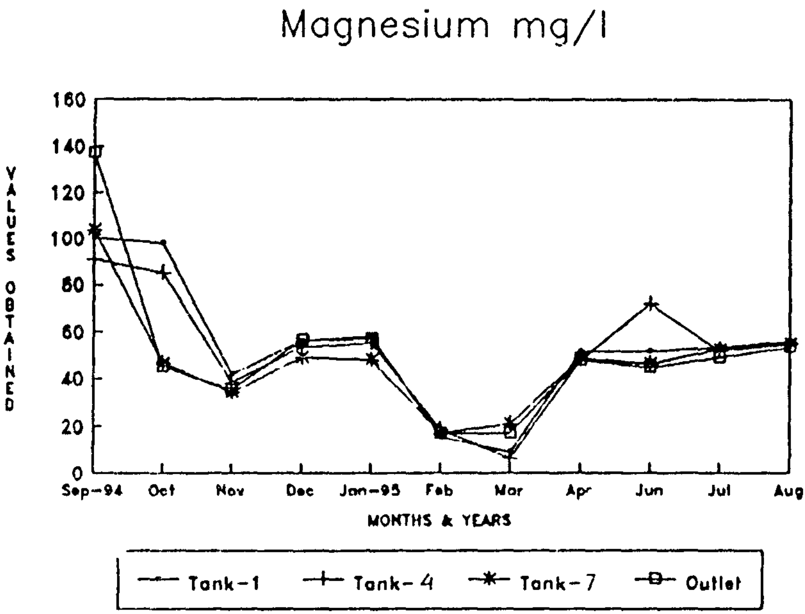


Fig. 7

Changes observed in Magnesium during the study period at Krishna Hospital waste treatment plant in different tanks.

Organic Dissolved Phosphorus

The organic dissolved phosphorus content of tank 1 ranges from 2.21 to 14.26 mg/L A sharp decline was observed on major occasions in tank 4, which coincides with hyacinth coverage. The organic phosphorus content of tank 4 varied from 0.30 to 10.81 mg/L. While in tank 7 it ranged from 1.09 to 11.60 mg/L. The outlet water always registered above 45 per cent decline in organic hosphorus content at compared to inlet water. The outlet concentration varied from 1.26 to 6.57 mg/L. Better hyacinth average always led to better reduction.

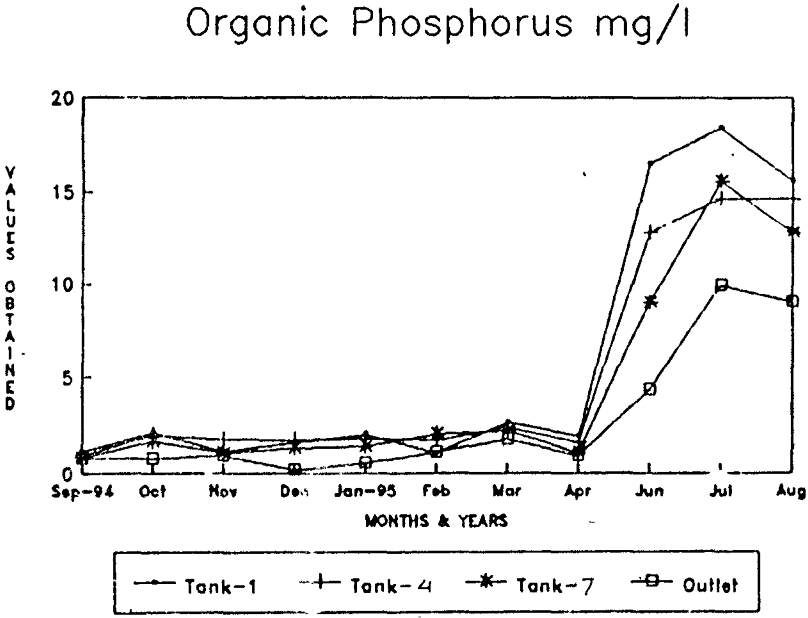


Fig. 8

Changes observed in Organic Desolved Phosphrous during the study period at Krishna Hospital waste treatment plant in different tanks.

Biochemical Oxygen Demand.

Biochemical Oxygen Demand (BOD) of the inlet varied from 72.0 to 160.0 mg/L. It declined sharpely in tank 4 except in September 1994 and October 1994. The concentration of BOD in tank 4 varied from 41.32 to 175.00 mg/L. The reduction observed also coincided with the haycinth coverage. In tank 7 the BOD concentration ranged from 21.0 to 128.0 mg/L. The reduction in tank 7 was much lower as compared to tank 4. A remarkable BOD reduction was observed in outlet on all the occasions except September 1994 (9.1%) and on most of the occasions BOD reduction was above 70 per cent and went upto percent age reduction was noted above 25 per cent on most of the occasions and reached as high as 64.30 per cent in February 95. The reduction obtained in outlet water coincided with higher hyacinth coverage from October 9 to February 95 (reduction noted was above 30 per cent).

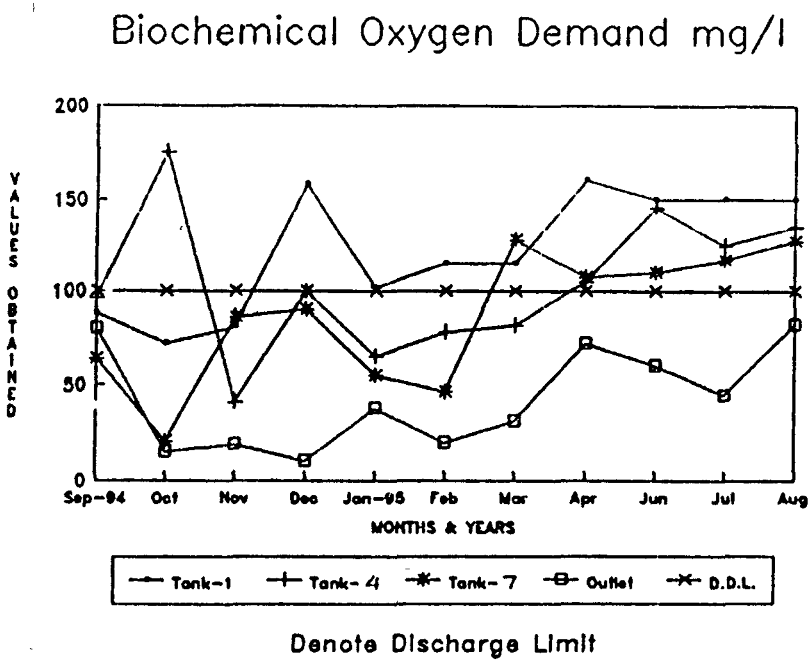


Fig. 9

Changes observed in Biochemical oxygen demand during the study period at krishna Hospital waste treatment plant in different tanks.

Organic Dissolved Nitrogen.

The organic dissolved nitrogen concentration in tank 1 ranged from 7.42 to 69.86 mg/L. A sharp reduction was noted on most of the occasions in tank 4 (being very high in December 1994). Here again hyacinth coverage coincided with intensity of reduction. The organic dissolved nitrogen in tank 7 declined considerably on two to three occasions out of eleven occasions. A sharp decline was noted in October 1994 (95.42%). The outlet concentration ranged from 1.27 to 43.08 mg/L. Excellent organic dissolved mitrogen reduction was observed on all the occasions in the outlet as compared to inlet as well in tank 7. The overall percentage reduction was above 35 per cent and went as high as 88.48 per cent in October 1994. This high reduction observed coincided with high hyacinth coverage.

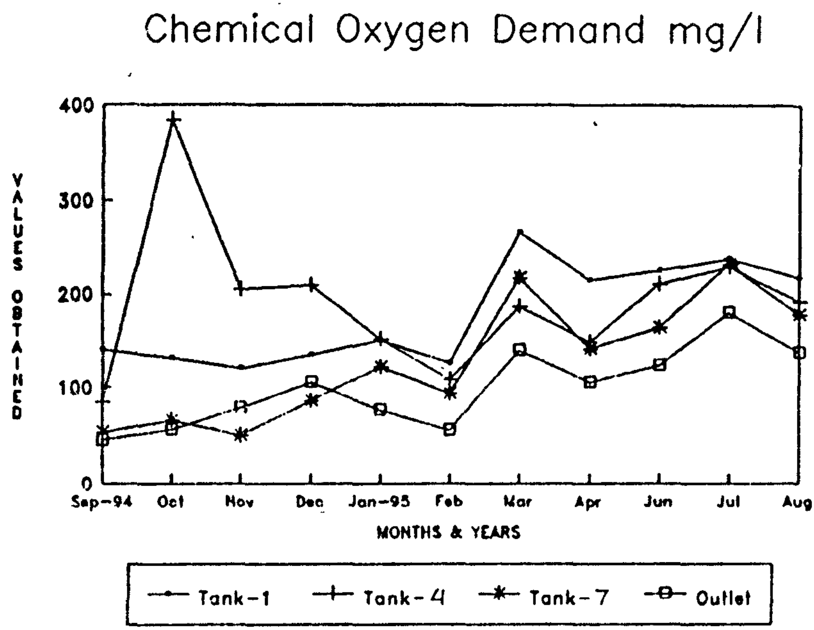


Fig. 10

Changes observed in Chemical oxygen demand during the study period at Krishna Hospital waste treatment plant in different tanks.

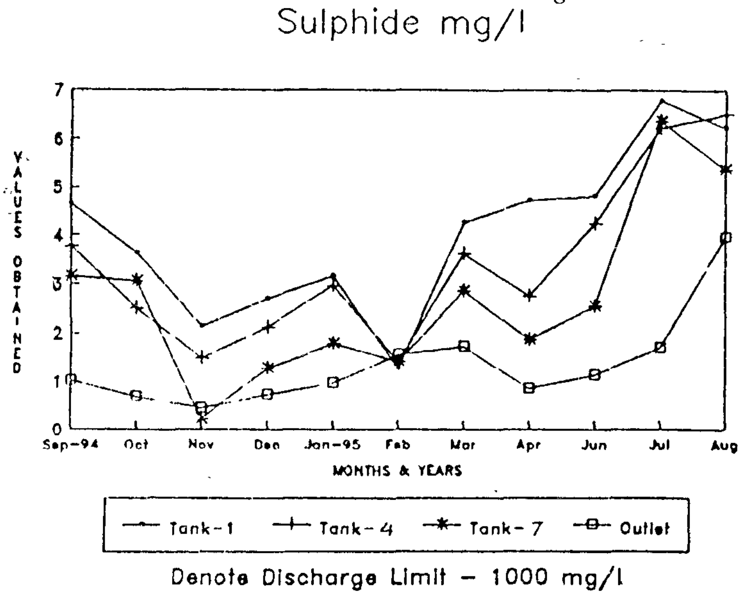


Fig. 11

Changes observed in Sulphide during the study period at Krishna Hospital waste treatment plant different tanks.

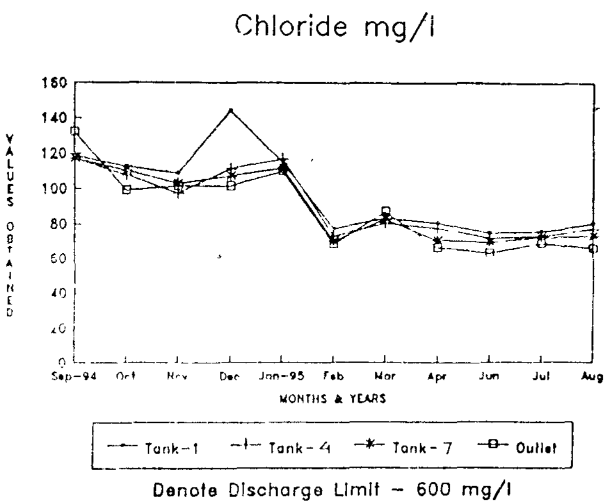


Fig. 12

Changes observed in Chloride during the study period at Krishna Hospital waste treatment plant in different tanks.

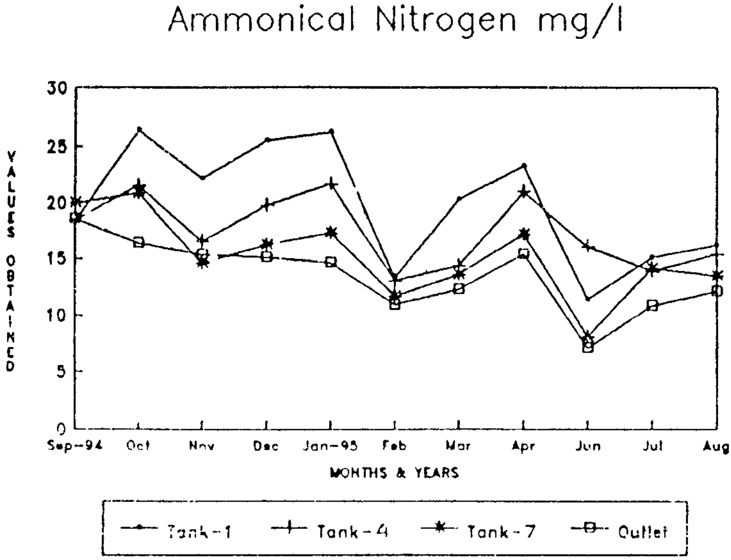


Fig. 13
Changes observed in Ammonical nitrogen during the study period at Krishna Hospital waste treatment plant in different tanks.

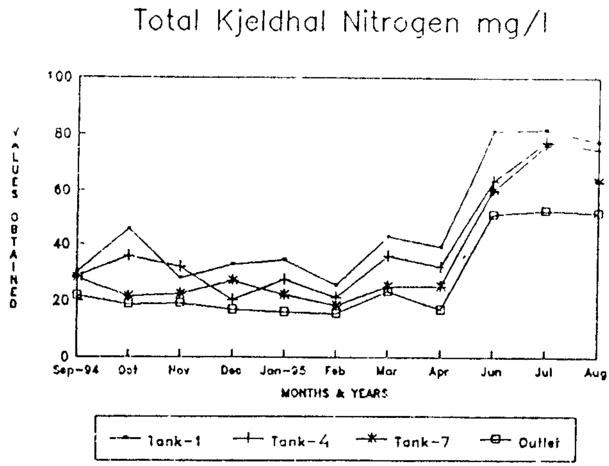


Fig. 14
Changes observed in Total Kjeldhal nitrogen during the study period at Krishna Hospital waste treatment plant in different tanks.

Nitrates

The nitrate contents of tank 1 varied from 1.85 to 7.68 mg/L. A sharp decline was usually observed in tank 4 where the concentration ranged from 1.65 to 6.75 mg/L. Further sharp decline was noted in tank 7 which was usually above 30 per cent ad went as high as 62.23 per cent in February 1995. The nitrates content of tank 7 ranged from 1.75 to 6.03 mg/L while in the outlet it ranged from 0.85 to 4.24 mg/L. A sharp nitrate reduction was observed on most of the occasions in outlet as compared to tank 7 and tank 1. The overall reduction was above 40 per cent on all the occasions as compared to tank 1 and went as high as 62.93 per cent in February 1995.

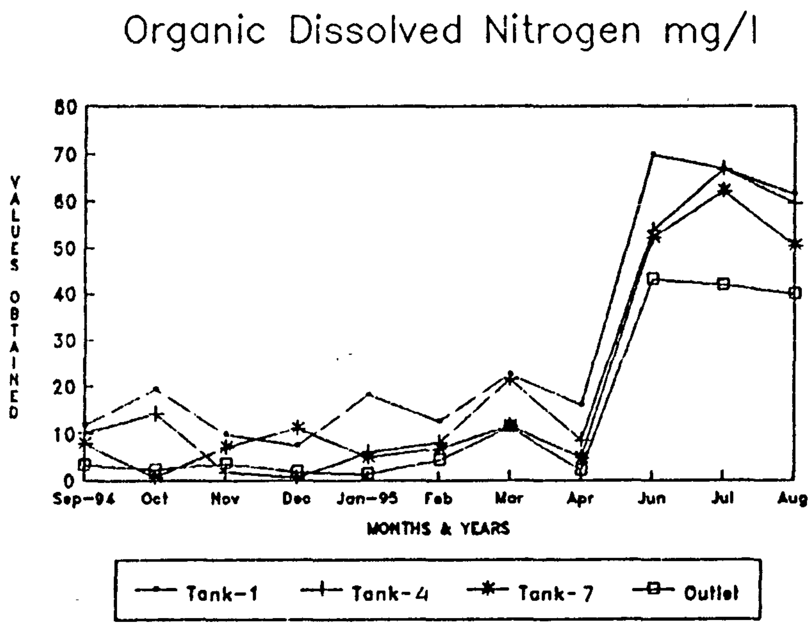


Fig. 15

Changes observed in Organic dissolved nitrogen during the study period at Krishna Hospital waste treatment plant in different tanks.

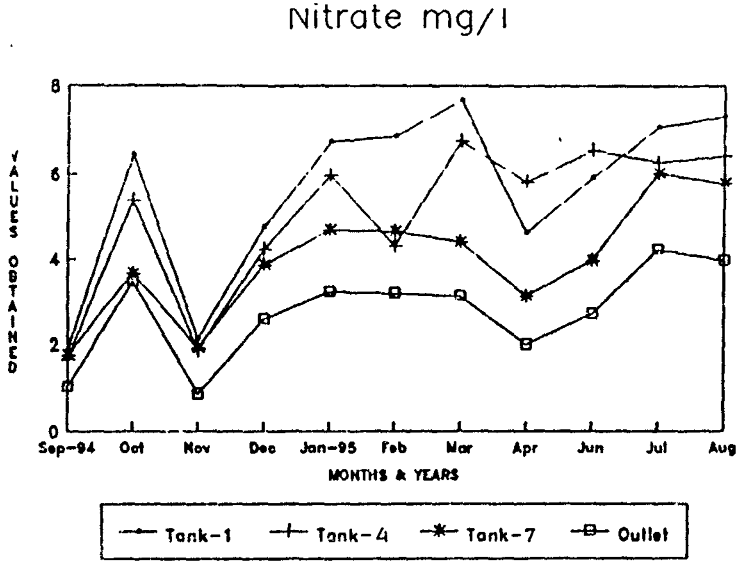


Fig. 16
Changes observed in Nitrate during the study period at Krishna Hospital waste treatment plant in different tanks.

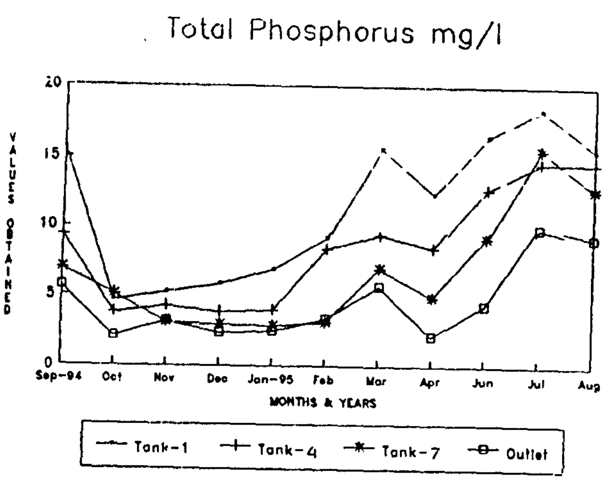


Fig. 17
Changes observed in Total phosphorus the study period at Krishna Hospital waste treatment plant in different tanks.

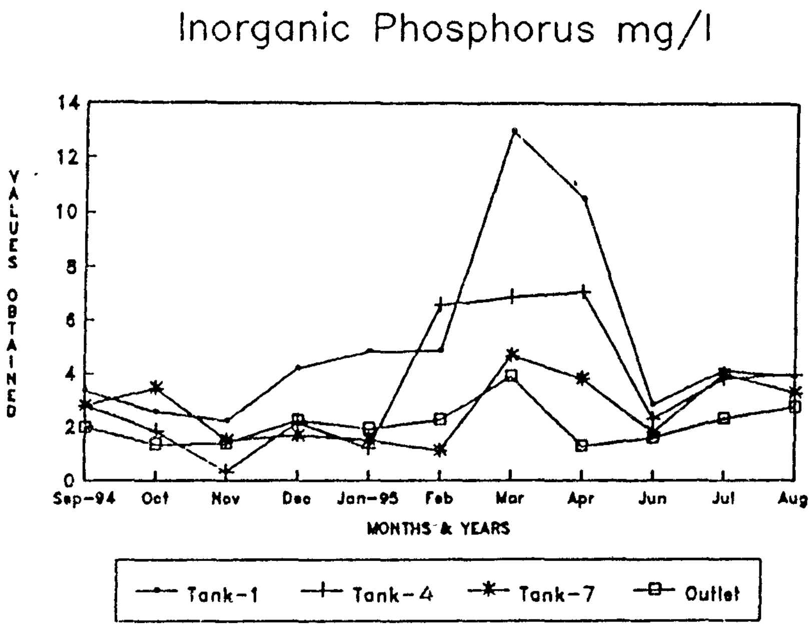


Fig. 18

Changes observed in Inorganic phosphorus during the study period at Krishna Hospital waste treatment plant in different tanks.

Total Dissolved Phosphorus

The total dissolved phosphorus content of tank 1 varied from 4.65 to 18.39 mg/L. A sharp reduction was observed in tank 4 on most of the occasions. The concentration of total phosphorus of tank 4 ranged from 3.78 to 14.64 mg/L, while in tank 7 it varied from 2.85 to 15.38 mg/L. Major reduction was observed in tank 7 (usually it above 20 per cent). The outlet concentration varied from 2.10 to 9.95 mg/L. A sharp reduction was observed in outlet as compared to tank 7 and tank 1. Reductions observed on most of the occasions in outlet were about 40 per cent and went as high as 82.81 per cent in April 1995. Minimum reduction was observed in August 1995 (42.17%).

Inorganic Phosphorus

The inorganic phosphorus contents of inlet water ranged from 1.06 to 4.13 mg/L. A sharp decline was observed in tank 4 on most of the occasions but was not found to be dependent on hyacinth coverage except in September 1994. A sharp decline was noted in tank 7 (0.916 to 3.98 mg/L). The outlet concentration varied from 0.14 to 2.78 mg/L. Excellent reduction was noted in outlet water as compared to tank 7 and tank 1. The outlet in comparison to inlet showed higher reduction (above 40 per cent) on major occasions and went as high as 91.14 per cent in December 94.

Oil and Grease

The concentration of oil and grease ranges from 5.16 to 34.54 mg/L. A sharp reduction was observed on most of the occasions except in November 1994 and July 1995 in tank 4. The oil and grease concentration in tank 7 ranged from 6.25 to 16.35 mg/L. A sharp decline was observed on most of the occasions which coincided with hyacinth coverage. The outlet concentration of oil and grease ranged from Nil to 2.15 mg/L. A sharp reduction was observed in most outlet concentrations during high water hyacinth coverage.

100 per cent reduction was noted in January 1995. Least reduction was observed in March 1995 (87.41%). The outlet concentration was below the standard limits laid down for the discharge of the waste water.

Particulate Phosphorus (P)

The concentration of tank 1 of particulate P ranged from 0.70 to 19.90 mg/L. A sharp decline was observed in tank 4 in particulate P concentration. The concentration of particulate P ranged from 0.57 to 11.97 mg/L. in tank 4, while in tank 7 it ranged from 0.60 to 10.43 mg/L. A sharp reduction was observed on most of the occasions. Higher (72.85%) reduction was observed in November 1995 which also coincided with high hyacinth coverage and least noted in August 95 (12.87%) which also coincided with least water hyacinth coverage. In tank 10 (outlet) the particulate P contents ranged from 0.96 to 7.47 mg/L. Excellent reduction was noted on most of the occasions in the outlet water.

Sulphate

The sulphate concentration of inlet (tank 1) water ranges from 21.82 to 218.42 mg/L. A sharp decline was observed in tank 4 almost on all the occasions. High reduction coincided with high coverage of water hyacinth. The tank 7 had sulphide content ranging from 13.27 to 160.29 mg/L. The reduction obtained in tank 7 was also correlated with high coverage of hyacinth. High reduction was observed (40.71%) in October 1994 and least reduction in June 1995 (8.47%). The outlet concentration of sulphate ranges from 4.73 to 136.36 mg/L. A sharp reduction was observed almost on all the occasions.

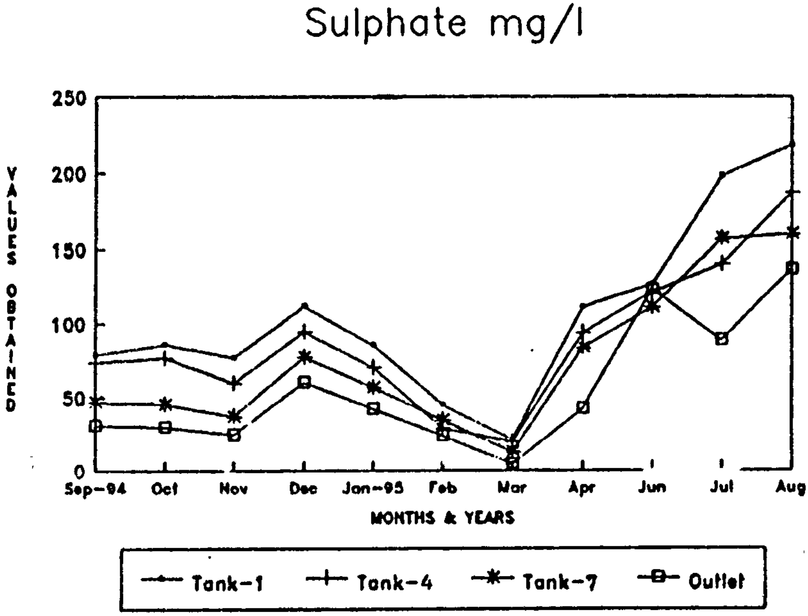


Fig. 19

Changes observed in Sulphate during the study period at Krishna Hospital waste treatment plant in different tanks.

The high reduction coincided with high coverage of hyacinth. Least reduction was noted in June 1995 (2.71%) which also correlated with low hyacinth coverage.

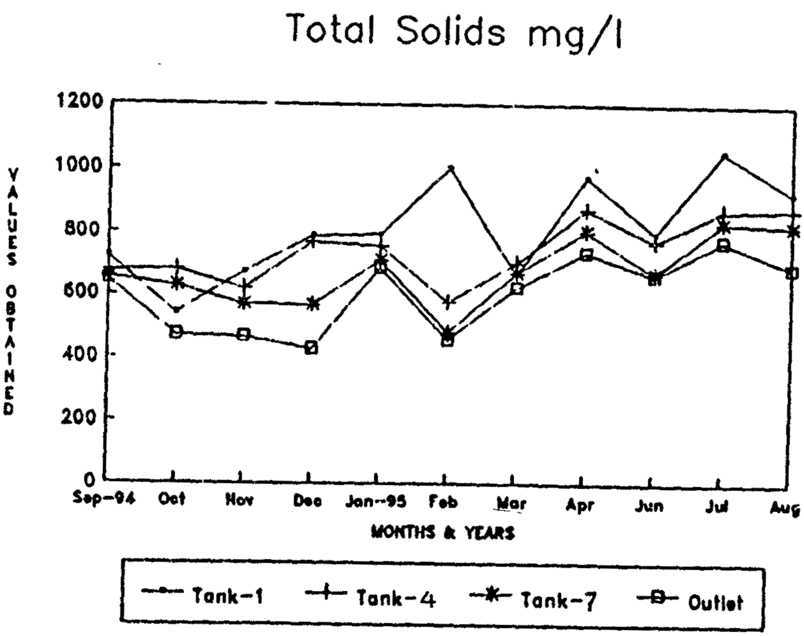


Fig. 20

Changes observed in Total solids during the study period at Krishna Hospital waste treatment plant in different tanks.

Discussion

It is important to highlight here basic mechanism of hyacinth based system (also referred as ATS-Aquatic Treatment System. In these systems wastewater is treated by passing it through one or more shallow ponds in which one or more species of aquatic macrophytes are grown. The scientific basis for wastewater treatment in these systeme is the cooperative growith of both the plants and the microorganisms associated with the plants. A major part of the treatment process for degradation of organics is attributed to the micro-organisms living on and around the plant root system. Once the micro-organisms are established on aquatic plant roots, they form symbiotic relationship in most cases with the higher plants. This relationship normally produces a synergistic effect resulting in increased degradation rates and removal of organic chemicals from the wastewater surrounding the root system. Microorganisms also use some or all metabolites released through plant roots as a food source. By each using the others waste products this allows a reaction to be sustained in favour of rapid removal of organic matter from wastewater. Electric charges associated with aquatic plant root hair also react with opposite charges on colloidal particles such as suspended solids causing them to adhere the plant roots where they are removed from the wastewater and slowly digested and assimilated by plants and microorganisms. Aquatic plants have the ability to translocate the oxygen from the upper leaf areas into roots producing an aerobic zone around the roots which is desirable in wastewater treatment.

The performance of hyacinth based waste treatment plant of Krishna Hospital and Medical Research Centre has to viewed in the light of certain facts :

1. The treatment plant was not optimally designed. It had BOD loading of 385.09 kg/ha/day which is considerably higher than the recommended loading of 50-100 kg/ha/day.
2. The relation time was only 3 days.
3. The vegetation was poorly managed.

The system had pH above 7 which usually increased during the treatment. It is frequently reported in the literature that water hyacinth brings the pH of the system near neutral either by increasing or decreasing it (Wolverton & McDonald 1979 (b) Mazumdar (1979) reports that hyacinth grows within a pH range of 4 to 9 with an optimum around 7. Wooten and Dodd (1976) also reported that during the treatment of sewage the pH was brought down from 7.2 to 6.7.

Relatively lower reduction in TDS was noted (Averaging around 20%) although upto 50 per cent reduction was noted during the same period. Danavade (1988) reported 4.13 to 48.21 per cent reduction in TDS it appears to be related to growth of water hyacinth as better reduction was noted during better hyacinth coverage.

A number of studies have shown that water hyacinth is capable of reducing suspended solids above 85% from the wastewaters. (Wolverton & McDonald 1979 b Miner estall 1971; shillinglow 1981; Trivedy & Gudekar 1985; Trivedy & Joag 1989) Reid and Strenbin (1979) studied the performance of two wastewater lagoon systems. During one year evaluation period, the overall TSS removal efficiency averaged around 76 per cent.

Danvade (1988) concludes that suspended solid reduction mainly depends on the types of waste and retention time used. In the present sudy maximum suspended solids reduction was obtained in June (90.55%). Operational disturbances, however, yielded abnormal values on few occasions.

A large number of authors have reported a high reduction in BOD of all kinds of wastewaters when treated with water hyacinth. BOD reduction has been found to vary seasonally as well as with detention period. Danavade (1988) from the same study area has reported 90.05% reduction in BOD in summer with the same kind of wastewater, Corresponding values for winter and monsoon were 83.13 per cent and 70 per cent. Maximum reduction obtained in summer can be easily ascribed to ideal temperature available for oxidation process. Wolverton and McDonald (1979b) have reported that the facultative wastewater lagoon with aquatic plants maintained the effluent BOD below the EPA discharge limit of 30 mg/1 throughout the year and the lagoon without water hyacinth showed 76 per cent reduction while with hyacinth it was 94 per cent.

In the present study extremely high reduction of BOD was observed and almost on all occasions the final value of BOD was below the discharge limit of Maharashtra Pollution control Board. BOD values were usually reduced by over 70 per cent (inlet BOD ranging from 72.0 to 160mg/1). BOD reduction was higher in warmer months and coincided with better hyacinth coverage. Such a phenomenal reduction in BOD by a hyacinth based system is highly promising. Similiar reduction was also obtained in COD values. Average COD of the waste was 179.2 mg/1 which came down to 100.13 mg/1 on an average basis and in terms of percentage reduction varied from 22.22 to 67.58 per cent. A large number of literature reports indicate a very heavy reduction in COD in the hyacinth based systems. (Nath et al. 1983; Trivedy & Gudekar 1985 and

Trivedy & Joag 1989) Although reduction in COD was exceptionally good at times, it remained near 50 per cent on an average basis. Orth and Saptoka (1988) have also found a better reduction in BOD in the hyacinth systems as compared to COD. While the above authors recommend further studies on this phenomenon, we feel it is due to poor vegetation management (which was beyond our control) and presence of certain complex organic substances in the waste. Gopal et al. (1984) have reported an increase in COD in ponds following prolonged stay of the plants in natural water bodies.

Conclusion

The use of aquatic plants for waste treatment especially sewage treatment has attracted global attentation in recent years. One of the main reasons for this development is that towns and small communities simply cannot afford the vast expenses involved in setting up physico-chemical treatment plants to provide advanced secondary or tertiary treatment. The conventional treatment methods are less flexible in terms of design modifications and are targetted primarily for removing BOD and to a lesser extent for removing P&N levels. The presence of heavy metals, hydrocarbons and toxic metals are not affected by most treatment plants. The communities in the developing and industrialized countries are moving towards greater material cycling and water reuse schemes as a means of addressing the water crisis and saving capital and operating costs. Establishment of an artificial wetland to provide various levels of water treatment is aesthetically economically and environmentally acceptable and compatible.

The present study, thus, has tremendous significance in view of precarious situation of wastewater treatment in India. In India even 50 per cent of the industries and towns do not have their own wastewater treatment plants. It is commonly known that not even 50 per cent of the existing systems work efficiently due to frequent failures, lack of trained personnel and expenditure on chemicals and power.

It is, thus, very important that in a country like India more and more such plants are established. Although a number of laboratory scale studies have been carried out in India (Trivedy and Gudekar 1985; Abbasi 1986; Trivedy and Joag 1989) but very few studies are available on pilot plants/field scale. (Abbasi 1986; Joglekar and Sonkar 1987)

It is hoped that more such studies shall be carried out in future.

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