AIT

Asian Institute of Technology
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COMPARATIVE STUDY OF AQUATIC MACROPHYTES FOR WASTEWATER TREATMENT

by

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A thesis submitted in partial fulfilment of the requirement for the degree of Master of Engineering

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ABSTRACT

One set of parallel oxidation ponds was used for comparing the treatment efficiency of pond system with and without water hyacinth in full-scale study under similar conditions. Experiments were performed from the last week of October till the last week of January , 1987. Mean COD loadings to the systems were 106 kg/(ha.d) and 98 kg/(ha.d) for the hyacinth pond and the free pond respectively. During the period of observation effluent concentrations in the hyacinth pond for hundred percent hyacinth coverage were 9 , 20 , 2 and 0.36 mg/L for SS, COD, TKN and TP respectively. The corresponding effluent concentrations in the free pond were 45, 94, 5.6 and 1.2 mg/L for SS, COD, TKN and TP respectively.

Mean mass of COD,TKN and TP were removed at 78, 76 and 74.8% respectively in the hyacinth pond system, whereas in the free pond system, mass COD, TKN and TP were removed at 20, 44.4 and 18.30% respectively.

At 100 % hyacinth coverage, mass COD, TKN and TP removed, in the hyacinth pond were, at 84, 79.6 and 79.4% respectively. In the free pond system mass COD, TKN and TP were removed at 24, 44.8 and 22% respectively. Hyacinth pond showed better performance than the free pond in removing SS, COD, TKN and TP from the wastewater.

Laboratory experiments were conducted for comparing the efficiency of aquatic plants namely water hyacinth, water lily and salvinia. The influent loading used were 41 and 86 kg COD/(ha.d). Results indicated that hyacinth pond system showed the best perfomance in removing pollutants followed by salvinia and water lily for the applied loadings.

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LIST OF SYMBOLS

Fulscale study

CODfe	Chemical oxygen demand in the free pond effluent
CODfi	Chemical oxygen demand in the free pond influent
CODhe	Chemical oxygen demand the hyacinth pond effluent
CODhi	Chemical oxygen demand the hyacinth pond influent
DOfe	Dissolved oxygen in the free pond effluent
DOfi	Dissolved oxygen in free pond influent
DOhe	Dissolved oxygen in the hyacinth pond effluent
DOhi	Dissolved oxygen in the hyacinth pond influent
SSfe	Suspended solids in the free pond effluent
SSfi	Suspended solids in the free pond influent
SShe	Suspended solids in the hyacinth pond effluent
SShi	Suspended solids in the hyacinth pond influent
TKNfe	Total Kjeldahl nitrogen in the free pond effluent
TKNfi	Total Kjeldahl nitrogen in the free pond influent
TKNhe	Total Kjeldahl nitrogen in the hyacinth pond effluent
TKNhi	Total Kjeldahl nitrogen in the hyacinth pond influent
TPfe	Total phosphate in the free pond effluent
TPfi	Total phosphate in the free pond influent
TPhe	Total phosphate in the hyacinth pond effluent
TPhi	Total phosphate in the hyacinth pond influent
TSfe	Total solids in the free pond effluent
TSfi	Total solids in the free pond influent
TShe	Total solids in the hyacinth pond effluent
TShi	Total solids in the hyacinth pond influent

Labscale Study

CODrw	Chemical oxygen demand in the raw waste water
CODsle	Chemical oxygen demand the salvinia pond effluent
CODwhe	Chemical oxygen demand in hyacinth pond effluent
CODwle	Chemical oxygen demand in water lily pond influent
DOrw	Dissolved oxygen the raw waste water
DOsle	Dissolved oxygen in the salvinia pond effluent
DOwhe	Dissolved oxygen in the hyacinth pond effluent
DOwle	Dissolved oxygen in the water lily pond influent
SSrw	Suspended solids the raw waste water
SSsle	Suspended solids in the salvinia pond effluent
SSwhe	Suspended solids in the water hyacinth pond effluent
SSwle	Suspended solids in the water lily pond influent
TKNrw	Total Kjeldahl nitrogen in the raw wastewater
TKNsle	Total KLeldahl nitrogen ın the salvinia pond effluent
TKNwhe	Total Kjeldahl nitrogen in the water hyacinth pond effluent
TKNwle	Total Kjeldahl nitrogen in the water lily pond influent
TPrw	Total phosphate in the raw waste water
TPsle	Total phosphate in the salvinia pond effluent
TPwhe	Total phosphate in the water hyacinth pond effluent
TPwle	Total phosphate in the water lily pond influent
TSrw	Total solids in the raw waste water
TSsle	Total solids in the salvinia pond effluent
TSwhe	Total solids in the water hyacinth pond effluent
TSwle	Total solids in the water lily pond effluent

I INTRODUCTION

Urbanization, increase in different types of industries, agricultural and livestock operations have all contributed to the gradual deterioration of our environment. Pollutants when discharged into the aquatic environment accumulate primarily in water and sediments, and in time the assimilation capacity of natural water bodies is exceeded by the amount of pollutants, the consequences of which are the dramatic reduction in the quality of waters, accumulation of toxicity in the aquatic food chain and bioaccumulation of carcinogenic and pathogenic substances in land animals. The situation calls for the control of pollutants at the source. Hence a technique which is inexpensive, innovative and versatile, is urgently needed for the numerous rural communities, small industries and feed-lot operations.

Aquatic treatment systems are becoming popular as an alternative to conventional systems due to relatively lower construction, operation and maintenance cost. The main function of aquatic plant in aquatic treatment system is to provide support for bacterial biomass which degrade the waste present in wastewater (STOWELL et al.,1980).

The quiescient water condition found in the aquatic treatment system are conducive to the sedimentation of wastewater solids, and bacterial and plant metabolism are of particular importance in the removal of soluble and colloidal biochemical oxygen demand (BOD) from wastewater. The adsorption and filtration potential of roots and stem of aquatic plant, the ion exchange and adsorption capacity of the sediments and emersed part of aquatic plant that reduce the perturbing effect of climatic variable contribute to the effectiveness of the system (TCOBANOGLOUS and SCHROEDER, 1985).

This study includes the comparison of treatment efficiencies of AIT wastewater treatment system with and without water hyacinths in full-scale.

The evaluation of responses of the pond systems with selected aquatic plants salvinia (Auriculata), water lily (Nymphaea) and water hyacinth (Eichhornia crassipes) in treating AIT wastewater, was also studied in laboratory scale.

1.1 OBJECTIVES OF RESEARCH

The objectives of the research were as follows.

- Evaluation of efficiencies of AIT wastewater treatment system with and without water hyacinths in removing total solids (TS), suspended (SS), chemical oxygen demand(COD), total Kjeldhal nitrogen (TKN) and total phosphorus (TP) in full-scale.
- To observe and compare the response of pond systems with the aquatic plants, salvinia (Auriculata), water lily (Nymphea) and water hyacinth (Eichhornia crassipes) for organic loading 41 kg COD/(ha.d) and 86 kg/(ha.d) under identical conditions in laboratory scale .

1.2 SCOPE OF THE RESEARCH

- AIT waste treatment system was used (particularly two aerobic ponds) in evaluating the treatment efficiency of the systems with and without water hyacinths at different coverages. Influent wastewater to ponds was AIT wastewater after being treated in anaerobic ponds.

- Laboratory experiments were conducted to evaluate the responses of the systems for organic loading 41 kg COD/(ha.d) and 86 kg COD/(ha.d) in removing the pollutants from the wastewater. Wastewater used was the AIT raw wastewater.

Parameters to observe the efficiences were suspended solids (SS) total solids (TS), Chemical oxygen demand (COD), total Kjeldhal nitrogen (TKN) and total phosphorus (TP) in full-scale and laboratory scale ponds.

II LITRETURE REVIEW

Waste stabilization ponds are economical for smaller communities due to lower construction and maintenance cost, without sacrificing the requirements of pollution control. The undesirable feature of the oxidation pond is algae laden effluent which raises the level of BOD or COD concentration in the receiving water-bodies. Wastewater standards, in most of the countries do not differentiate between the suspended matter and algae. Smaller communities canot afford the advanced treatment methods which are highly efficient to reduce the level of contaminants in the receiving waterbodies. So, the methods which are less expensive without sacrificing the desired level of pollution control have to be developed.

The use of aquatic plant in removing the contaminants from the water can be traced back to the publication of DYMOND (1948) which suggested using water hyacinths to remove nutrients from wastewater effluent.

SHEFFIELD (1967) was the first man (as reported by GOPAL and SHARMA, 1981) to demonstrate the use of water hyacinth for nutrient removal. He reported 80 percent reduction in NH3-N when aerated effluent passed through water hyacinth pond with a retention time of ten days. Phosphates were reduced initially upto 51 % but decreased to only 20 % after one month due to release of phosphorus from decaying plants.

CLOCK (1968) reported that high removal of nitrogen and phosphorus could be obtained when secondary waste-water effluent was passed through dense mat of growing water hyacinths at a detention time of 5 days. The removal efficiency was 75 % for NO3-N and 61 % for PO4 from a mixture of extended aeration effluent and raw wastewater. As reported by CORNWELL et al. (1977), EDWARD (1960) had found out that the water hyacinth was capable of using 18 kg PO4 per metric tons of hyacinths (36 lb/ton) and 96 kg N per metric ton of hyacinths (191 lb/ton).

SHEFFIELD and FURMAN (1969), as reported by CORNWELL et al. (1977) had found out that NO3-N was reduced by 92 % primarily by anaerobic denitrification and NH3-N was removed by 35 % by plant uptake when secondary effluent was passed through water hyacinth pond followed by aeration and coagulation (with 2 : 1 recirculation).

MINER et al. (1970) reported that 10.4 Kg of NH3-N and 7.72 Kg of PO4 and 11.4 Kg of total Kjeldahl nitrogen/acre (0.406 ha) with a 102-day detention time in ponds 460 mm (18 in) deep.

SCARBROOK and DAVIS (1971) studied the effects of wastewater effluent on the growth of 5 vascular aquatic plants : water hyacinth, alligator weed curly pond weed, ageria and slender naiad. Of the five, hyacinth responded to extranutritional level available in wastewater effluent.

ROGER and DAVIS (1972) estimated that one hactare of water hyacinths were able, under optimum condition to absorb the nitrogen and phosphate contributed by approximately 800 people.

CORNWELL et al. (1977) found out that the nutrient removal capability of water hyacinth was directly related to the pond surface area. To remove 80 percent of total nitrogen 2.1 ha of water hyacinth were needed per 3800 m^3/d (1 mgd). The corresponding phosphorus removal was 44 %.

DINGES (1978) reported that controlled culture of water hyacinth basin was effective in removing suspended solids and dissolved solids from stabilization pond effluent.

Clear, high quality of water was obtained which was low in nitrogen and fecal coliform bacteria. BOD, SS were removed at 97 and 95 % respectively. COD removal through plant and culture basin was 90 %. Mean effluent BOD, TSS and total nitrogen concentration were <10, <10 and <5 mg/L. respectively.

WOLVERTON and MCDONALD (1979) studied the removal efficiency of a lagoon (single cell) with an surface area of approximately 2 ha and average depth of 1.22 m. The average flow rate was 475 m^3/d and retention time of 54 days. Comparison of removal efficiency of system in the background period (without plants) and during water hyacinth experimented period is explained in the literature.

LAKSHMAN (1979) used aquatic plants Bulrush (Scirpus species) and cattail (Typha species) to purify municipal sewage in experimental tank (5.5m X 3.7m X 3.7m). He reported that high rate of purification up to 98 % were achieved in <20 days. The plant showed unabated ability to remove nutrients from the wastewater.

DINGES (1979) reported that water hyacinth system is capable of producing an effluent having a mean concentration of <10 mg/L of BOD and TSS. The percent reduction of BOD , TSS, COD and TN were respectively 87, 93, 72 and 63 % in pilot-scale studies. And in full-scale hyacinth treatment system the reduction of BOD and TSS were observed to be 71 and 78 % respectively. He also reported that hydraulic loading is the most critical consideration in culture basin design.

The extensive works of TCHOBANOGLOUS et al. (1979), WOLVERTON (1979), and O'BRIEN (1981) may be referred for the design of wastewater treatment system using aquatic macrophytes. Work of O'BRIEN (1981) gives the details of design of performance characteristics of aquatic macrophyte wastewater treatment systems in different parts of U.S.A..

TCHOBANOGLOUS et al. (1979) have dealt with the concept, design and use of aquatic system and the implications.

The work of WOLVERTON (1979) includes the general background of the research findings of the National Aeronautics and Space Administration's vascular aquatic plant Program using higher plant such as the water hyacinth (Eichhornia Crassipes) duck weed (Lemna Species and Spirodela Species) to treat domestic wastewater.

MCDONALD and WOLVERTON (1980) have reported a 3-year study on existing one cell facultative sewage lagoon (3.6 ha) with BOD loading rate 44 kg/(ha.d). The work includes the study of the efficiency of facultative

lagoon with and without water hyacinths in 3- consecutive year. They reported that during the period with water hyacinths the effluent BOD and TSS were 23 and 6 mg/L respectively and without hyacinths the effluent BOD and TSS were 52 and 77 mg/L respectively. Fig. 2.1 and Table 2.1 show the effectiveness of water hyacinths in wastewater treatment system.

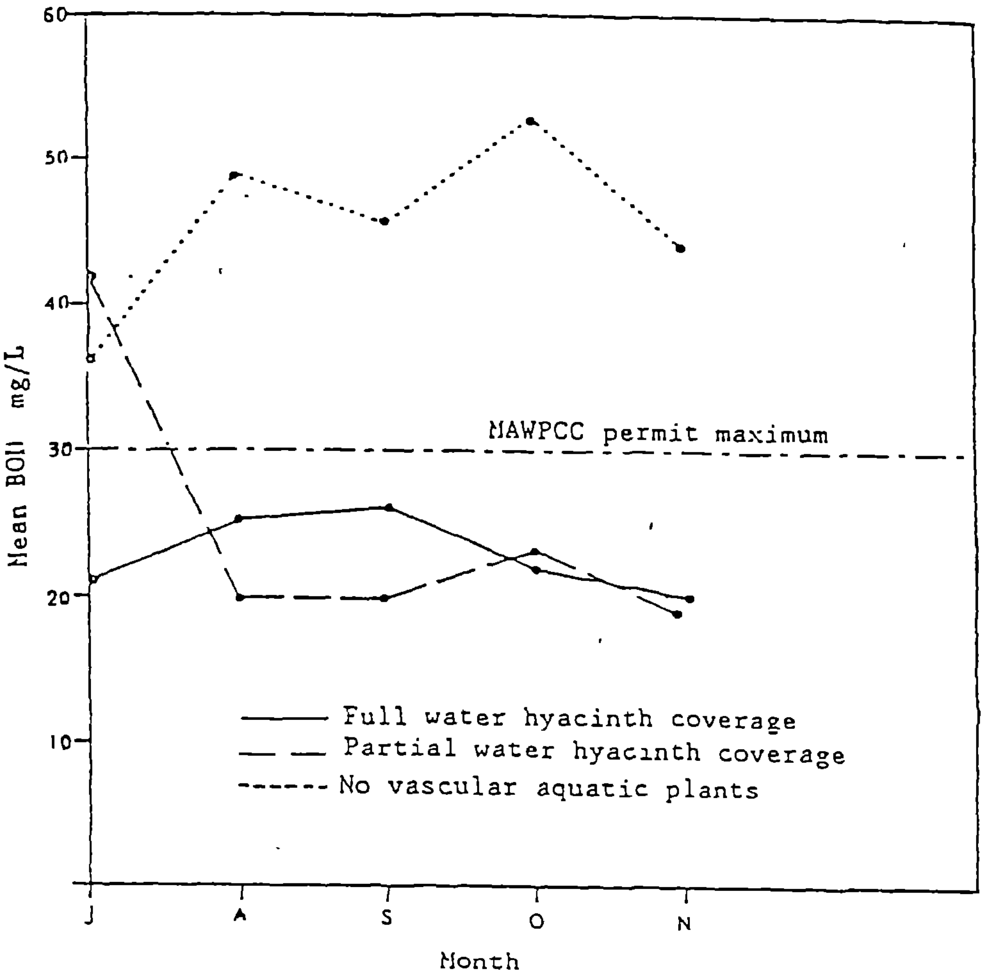

Fig. 2.1 Monthly mean 5-day biochemical oxygen demand concentration during 3 study periods.

Table 2.1 Five-month experimental means for each parameter during the three consecutive periods (Source: MCDONALD and WOLVERTON, 1980)

Parameter	100 % Hyacinth cover		3 % Hyacinth cover		% Hyacinth cover	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
BOD5,mg/L	161.0	21.0	121.0	25.0	127.0	52.0
TSS,mg/L	125.0	6.0	85.0	57.0	140.0	77.0
TKN,mg/L	30.3	14.4	26.2	14.8	28.2	18.7
TP,mg/L	8.5	7.9	7.8	8.2	8.1	8.6
TOC,mg/L	93.0	40.0	73.0	60.0	66.0	72.0
DO,mg/L	1.5	0.6	2.2	0.8	2.1	4.4
PH	7.3	7.0	7.1	7.1	7.3	7.7
Discharge m/d)		935.0		1240.0		957.0

The role of aquatic macrophytes, water hyacinth (Eichhornia crassipes), water lettuce (Pistia stratiotes), pennyworts (Hydrocotyle umbellata), duckweeds (Lemna minor and Spirodela polyrhiza), azolla (Azolla Caroliniana), salvinia (Salvinia rotundifolia) and a submerged macrophytes, egeria (Egeria densa) was studied by REDDY and BUSK (1985). The removal of nitrogen was in the order of water hyacinth > water lettuce > penny wort > Lemna > Salvinia > Spirodela > egeria, during the summer season, but in the winter the removal was in the order of hyacinth Lemna, water lettuce, spirodela, salvinia and egeria. Phosphorus removal was highest by water hyacinth and egeria in summer but pennywort and Lemna showed high P-removal in the winter.

It is obvious that most of the researchers have concentrated their research on a single plant, water hyacinth. Only a few literature are available in dealing with other types of aquatic macrophyte which may be alternatives to water hyacinth system depending on the availability of aquatic plants and the level of pollution to be reduced.

Here, the author studied the removal efficiency of aquatic plants (selected), water hyacinth, water lily and salvinia in laboratory scale. Also the comparison of AIT wastewater treatment system's efficiency was done with and without water hyacinths, as no comparison was made with and without water hyacinth under the similar environmental conditions.

2.1 Types of aquatic plants

Aquatic macrophytes in aquatic treatment system are classified into 3 groups namely emergent, floating and submersed (Fig. 2.2). Aquatic macrophytes in use are reported in Table 2.2.

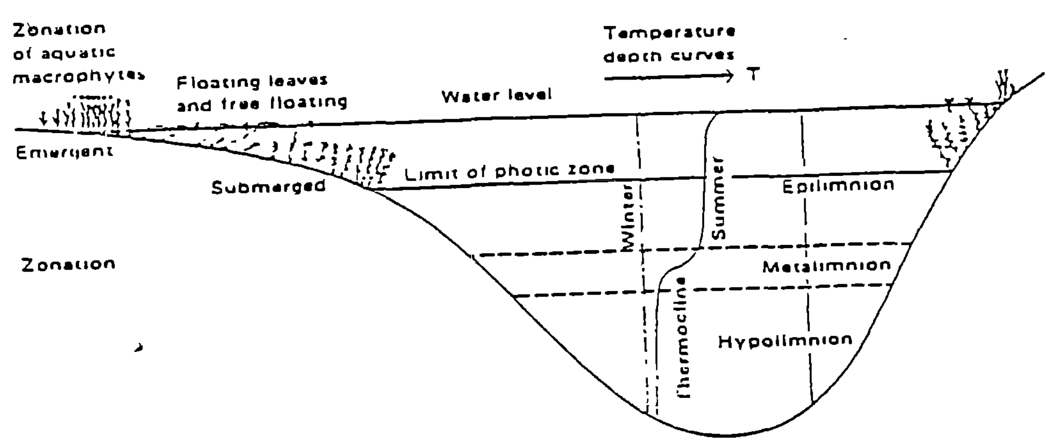

Fig.2.2 Diagram of a lake showing zonation of aquatic weeds (Source: MITCHELL, 1974)

2.2 Selection of aquatic plants

Selection of aquatic plant was made by tentatively observing the efficiency in removing COD from water in the existing canal within the AIT campus. Samples were collected from the upstream and downstream of the canal and were analyzed for COD in Environmental Engineering Laboratory, AIT. The observed efficiency for the COD removal by the plants, water hyacinth, salvinia, water lily and water spinach were 50%, 38%, 20% and 18% respectively. Water hyacinth, salvinia and water lily were selected for study purpose, based on removal efficiency, aesthetic value and availability.

2.2.1 Water hyacinth (Eichhornia crassipes)

Water hyacinth (Fig. 2.3) is one of the prominent aquatic weeds in the tropical and the sub-tropical areas of the world. Researchers have recently recognised that with the proper management water hyacinth can be effectively used to reduce pollutant levels of water bodies (STOWELL et al., 1981) and potentially use the resulting mass for production of gaseous fuels (WOLVERTON and McDONALD, 1981) and feed (BAGNALL et al., 1974).

2.2.2 Salvinia (Auriculata)

It is a free floating aquatic weed which has colonised in several parts of world particularly in tropical region. It has extensive root systems for supporting bacteria and leaves to provide shade for preventing algae growth.

2.2.3 Water Lily (Nymphaea)

This aquatic plant has colonised in tropical and sub-tropical region of the world. It has circular leaves with deep notch to which a stem is attached, beautiful blue or red flowers. Bacterial biomass can be attached to stem and leaves (Fig.2.4).

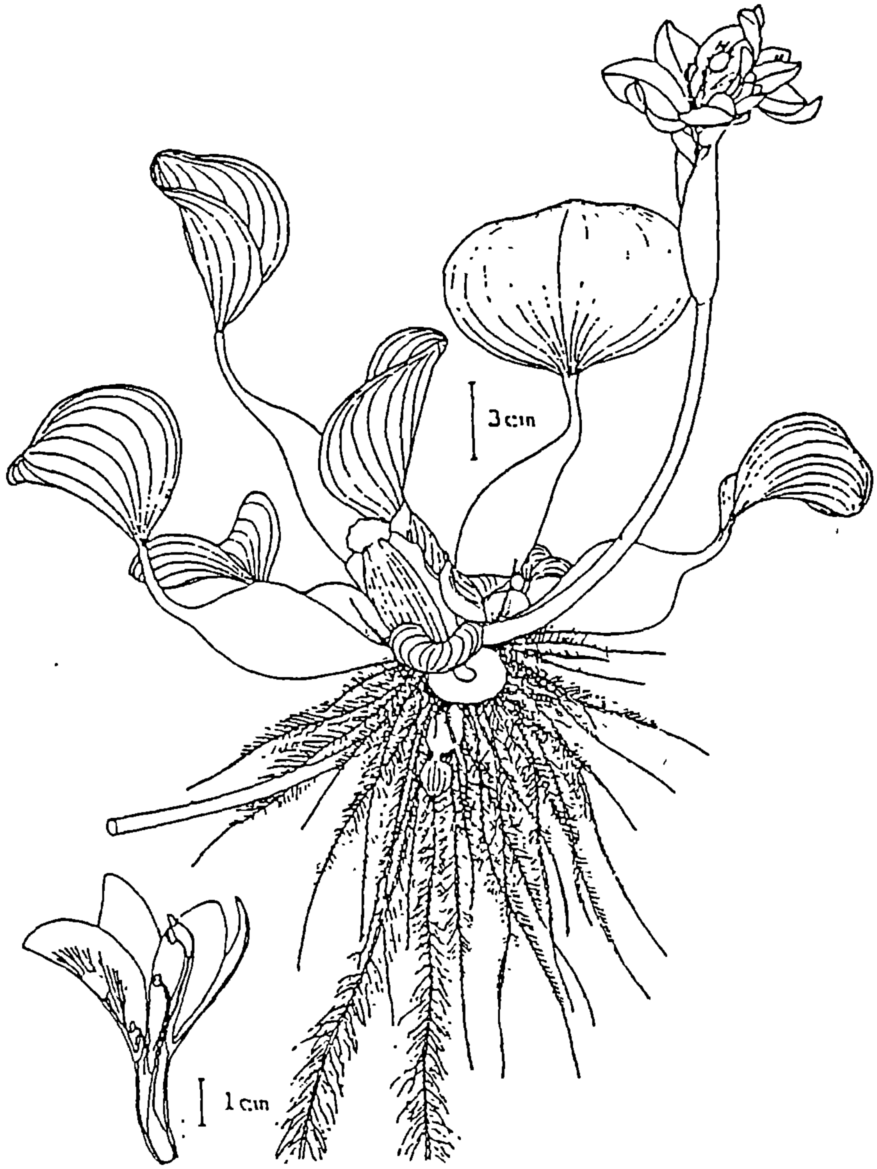

Fig. 2-3 Water hyacinth (Eichhornia Crassipes)

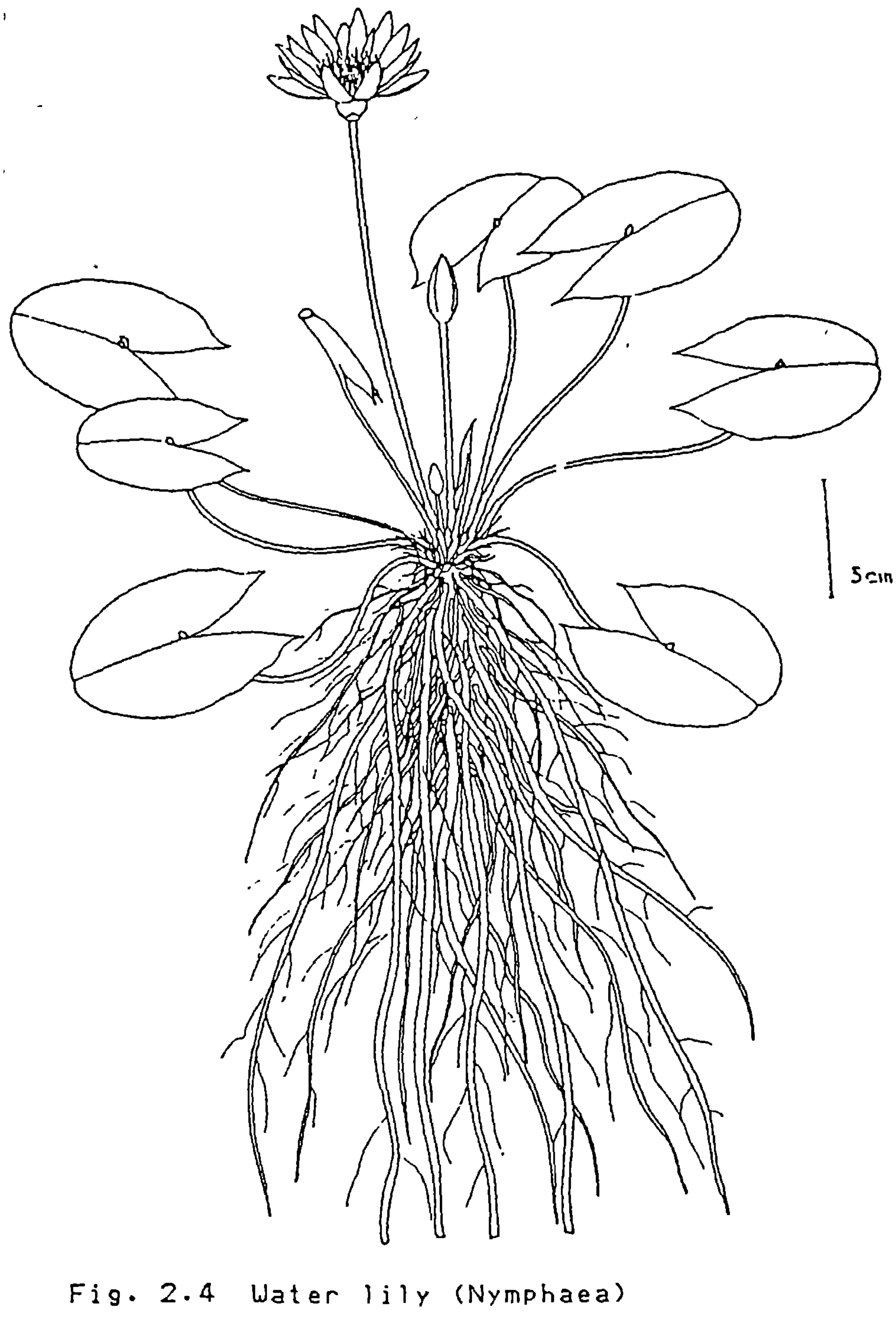

Fig. 2.4 Water lily (Nymphaea)

Table 2.2 Potential aquatic plants for use in aquatic treatment systems (TCHOBANOGLOUS et. al., 1979 and addition)

Organism	Probable role and remarks
Floating aquatic plants	
Water hyacinth (Eichhornia species):	Its extensive root system serves as a mechanical filter and a support structure for bacteria. Mats of hyacinth attenuate sufficient light to prevent the growth of algae.
Water primrose (Ludwigia species):	The root system is not as extensive as that of the hyacinth nor is the floating vegetative mat as dense. Water primrose attenuate sufficient light to prevent algae problems.
Duckweed (Lemna species):	The root system of this plant is very small and will not support an appreciable mass of bacteria. Duckweed grows in dense mats that effectively restrict gas transfer and attenuate light.
Emergent aquatic plants	
Cattails (Typha species):	The submerged portion of a cattail stand serves as a mechanical filter and a support structure for bacteria. Algae will not grow in dense cattail stands. Cattails successfully winter-over even in colder climates.
Bulrush (Scirpus species):	Essentially as noted above for cattails except that stands of bulrush tend to be more open. Bulrusshes may be more adaptive than cattails to wastewater environments.
Reeds (Phragmites species):	Reeds are similar to cattails and bulrushes but tend to grow in comparatively open stands. In certain situations algae growth in reed stands could occur.
Submerged aquatic plants	

Algae	This broad grouping of very small unicellular plants has very high production rates, but are difficult and costly to remove from the water once grown. During photosynthesis, molecular oxygen is released into the water at the expense of increasing the BOD of the water.
Pond weeds (Potamogeton species)	The value of pondweeds as support structure for bacteria is variable from species to species as is their potential to compete with and shade out algae. Because these plants are for the most part submerged in the wastewater environment, there is greater inherent chance of plant population instability caused by fluctuations in wastewater quality.

Other possible aquatic plants

Water milfoil (Myriophyllum)
Salvinia (Molesta)
Salvinia (Auriculata)
Water lily (Nymphaea)
Water spinach (Ipomoea)
Pistia (stratiotes)
Coontail (Ceratophyllum)

2.3 Design parameter for aquatic treatment system

The design parameters for the aquatic treatment system used are as follows:

2.3.1 Detention time

Hydraulic detention time, generally expressed in day is the most widely used parameter for aquatic treatment system because of the fact that majority of the performance data reported in the literature correlated to detention time.

2.3.2 Organic loading rate

It is the mass of the organic material divided by the surface area of the system per unit time. It is expressed as kg (BOD or COD)/(ha.d). It is a function of flow rate and concentration of the organic matter. If the organic loading is increased odour problem may arise in the system.

2.3.3 Hydraulic loading rate

It is the volume of wastewater applied per day divided by the surface area of the aquatic system. Since aquatic system are operated in continuous flow system, hydraulic loading is not a pertinent parameter.

2.3.4 Hydraulic application rate

It is not widely used but offers a better unit of comparison for system performance data. It is the gage of fluid velocity which seems to have a significant role in removal mechanism operative in aquatic treatment system.

Table 2.3 - Functions of aquatic plants in aquatic treatment systems (STOWELL et al.,1980)

PLANT PARTS	FUNCTION
Roots and/or stems in the water column	1. Surfaces on which bacteria grow. 2. Media for filtration and adsorption of solids.
Stems and/or leaves at or above the water surface	1. Attenuate sunlight and thus can prevent the growth of suspended algae. 2. Reduce the effects of wind on the water. 3. Reduce the transfer of gases between the atmosphere and water. 4. Transfer of oxygen from leaves to the root surfaces.

2.4 Removal mechanisms of pollutants in aquatic treatment system

From the result of numerous researches, it is obvious that aquatic treatment processes are capable of producing lower concentrations of BOD, SS and total nitrogen. The removal of phosphorous, heavy metals, refractory organics and pathogens is dependent on site and wastewater characteristics. Function of aquatic plants in aquatic treatment systems is shown in Table 2.3.

2.4.1 Removal of BOD

The BOD removal is higher in the summer season when the bacterial support (root and stem of plant) is the greatest. In the winter, it is generally lower because of slower metabolic activities of micro-organisms and plants. When plants die bacterial support is lost, thereby reducing the mass of bacteria for degrading the wastes. Settleable BOD is removed by sedimentation and soluble BOD is removed as a result of metabolic activities of bacteria and plants.

2.4.2 Removal of suspended solids

The removal process is the physical phenomena which prevents light, thereby, preventing the growth of algae which is the major constituent of effluent suspended solids.

2.4.3 Removal of nitrogen

The removal mechanism operative in aquatic treatment system is alternate bacterial nitrification and denitrification, ammonium volatilization, plant uptake, and sedimentation (STOWELL et al. 1981). Depth of 3 m below water surface in which nitrification occur is a function of BOD loading rate and oxygen flux into the aquatic system. For denitrification to occur, there must be no dissolved oxygen, neutral pH, and supply of carbon (adequate), effective surface area of bottom sediments and potential for the produced N2 or N2O gas to escape to atmosphere.

2.4.4 Removal of phosphorus

The significant removal of phosphorus is due to chemical adsorption and precipitation reaction in sediments and water column waterface. Plant uptake does not have any significant removal. Phosphorus removal data are not consistent, what makes the phosphorus removal in aquatic treatment system is not known.

III METHODOLOGY

The comparison of aquatic plant in removing the polutants from the wastewater was made on full-scale and laboratory scale ponds.

3.1 Full-Scale Ponds

AIT has its own Pond Treatment System for the wastewater discharged from campus. It has two parallel sets of ponds in series. The final effluent from the pond is discharged into near by canal. Two oxidation ponds (Fig 3.1) were used to compare the efficiency of the oxidation ponds with and without water hyacinth. These oxidation ponds receive the wastewater discharged from the facultative ponds (now performing completely as anaerobic ponds) southern pond was tested with water hyacinth and nothern pond was used as free pond (without hyacinth) water hyacinth were collected from the canal nearby Bankhan, 4 km distant from AIT; and put on the pond. To prevent the effect of wind which causes the plant to move, floatable plastic rope was used as a temporary barrier. To facilitate sampling procedure baffles were constructed in the influent and effluent channel of the ponds.

To measure the influent and effluent flowrate calibrated V-notch weir used with automatic level recorders. Grab samples from the influent and effluent channel of the pond were collected twice a week and analysed in Environmental Engineering Laboratory according to Standard methods for Water and wastewater (1985).

Analyses and sampling was done once the hyacinth coverage was 20% of the pond area. Experiment were performed from the last week of October 1986 till the first week of February 1987, hyacinths were put on pond on last week of September, by the first week of January, 100% coverage was achieved.

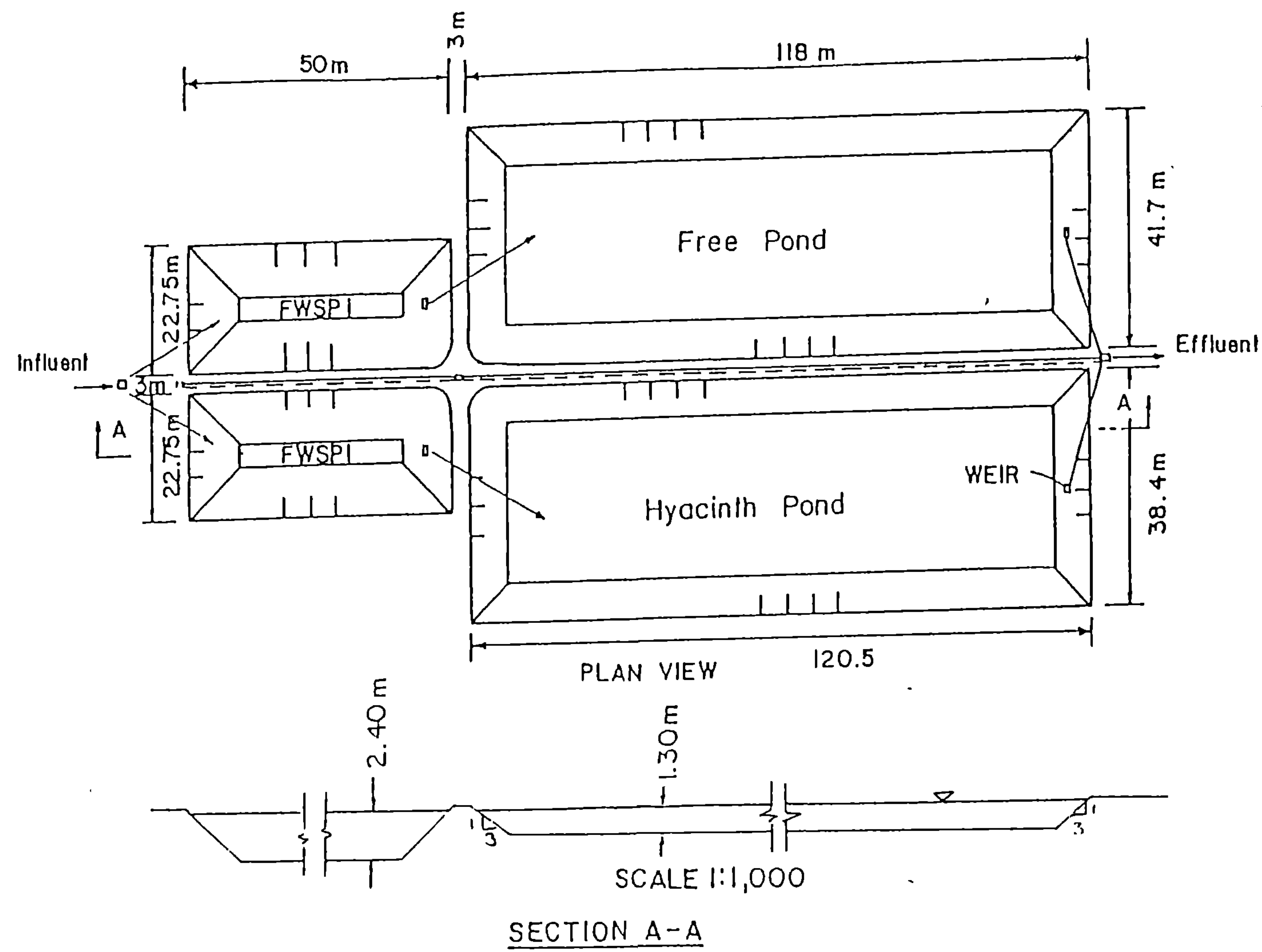

Fig 3.1 Layout of AIT waste stabilization ponds

3.2 Laboratory Scale Pond

Three concrete ponds (Figure 3.3) were used for comparing the pond efficiences with hyacinth, water lily and salvinia. These ponds were already existing, so they were modified according to this study purpose. Baffles were constructed to reduce the short circuit in the ponds. Small wooden baffles were installed near the effluent pipe to avoid suspended matters in the effluent. Influent wastewater used was AIT raw wastewater. Constant head tank which received wastewater continuously from sewage feed tank was used to feed to the three ponds by, manually, controlling the flow rate. Schematic diagram of laboratory scale is shown in Fig. 3.2. Methods of analyses of different parameters adopted according to Standard Methods for Water and Wastewater (1985) are shown in Table 3.1.

Table 3.1 Parameters and methods of analysis

Parameter	Method of analysis
TS	Drying at 103 oC after evaporating on water bath
SS	Drying at 103 oc for 1 hour
COD	Potassium dichromate
TKN	Kjeldahl Method
TP	Stannous Chloride Method

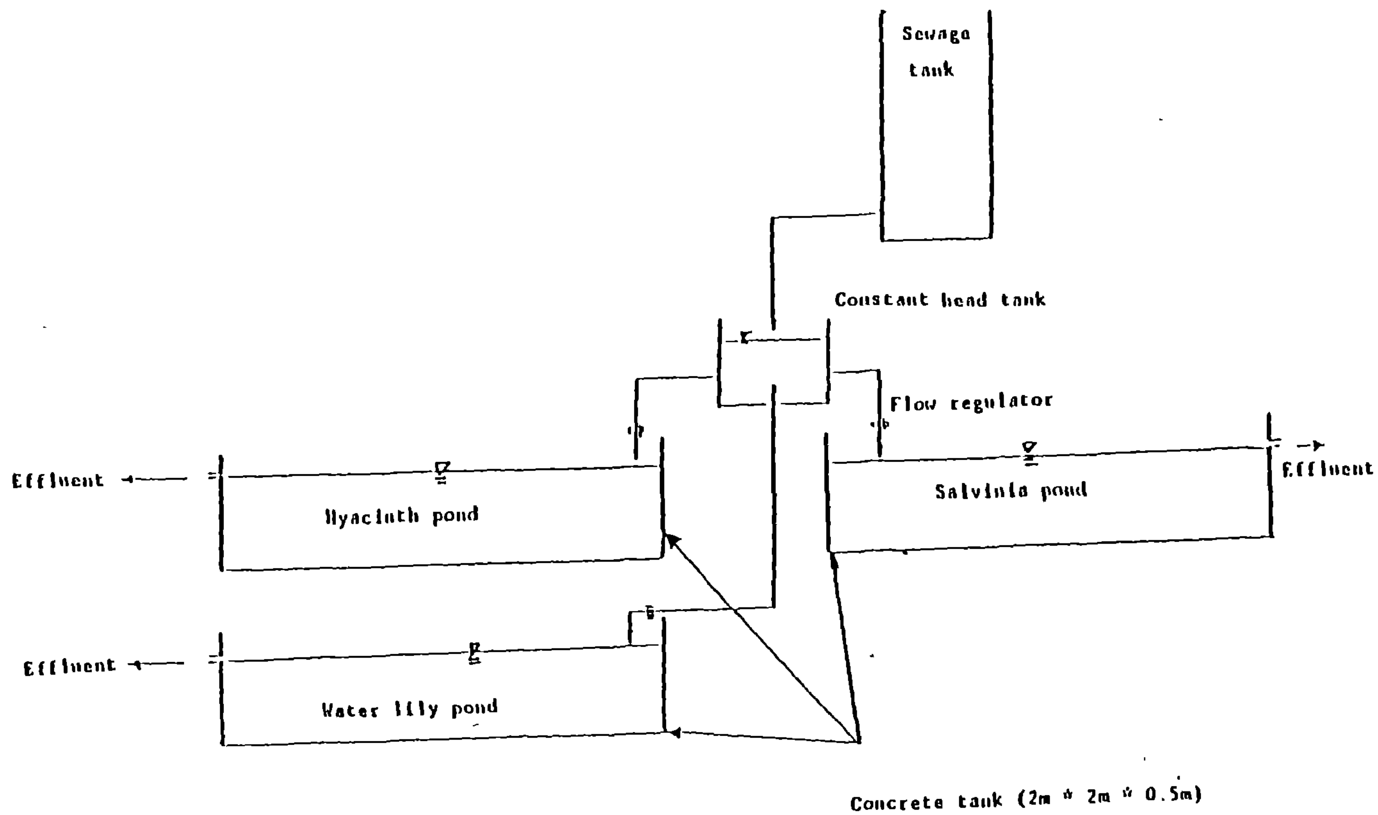

Fig.3.2 Schematic diagram of laboratory scale ponds

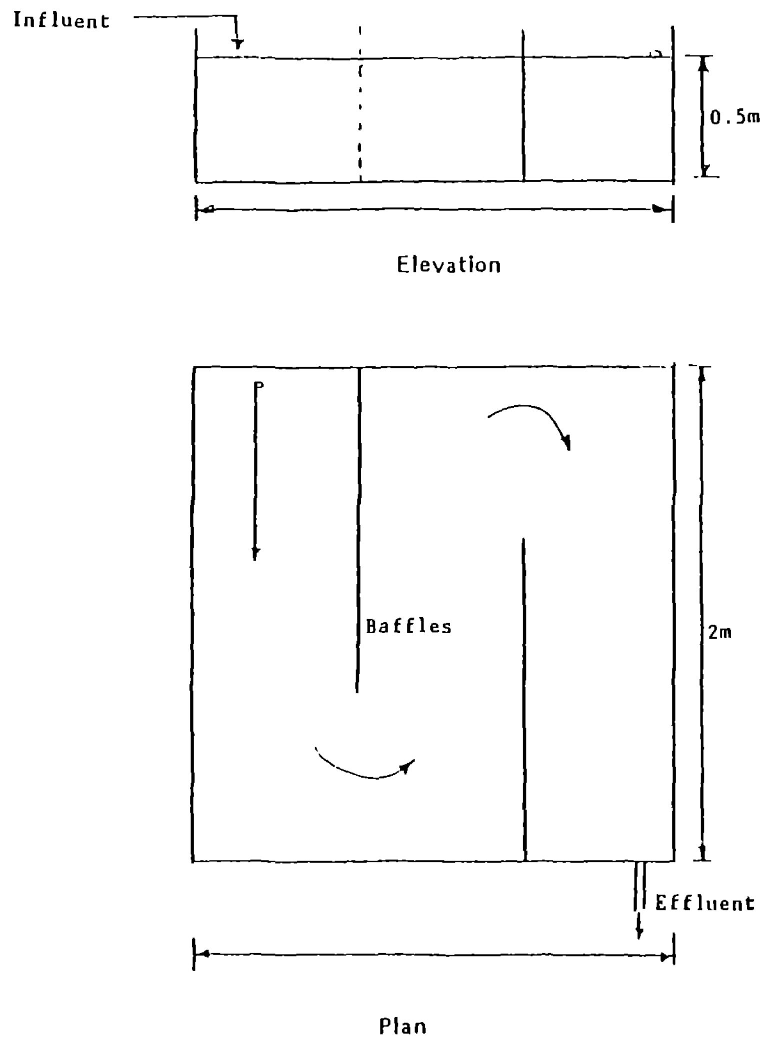

Fig.3.3 Dimension of laboratory scale pond

IV RESULTS AND DISCUSSION

4.1 Pond with and without water hyacinths

Wastewater treatment system are expected to provide the effluent that meet defined standards. Depending on the condition and needs, the standards differ in certain cases and but are mostly similar. The two most important contaminants in domestic sewage are BOD or COD and suspended solids. The performance of the system varies in many ways, some of which can not be explained properly.

Hence, effluent values of concerned water quality parameters should be lower than the defined standards.

Samples from the influent channel and effluent channel of the free pond and the hyacinth pond were collected and analysed. The graphs (Effluent concentration vs. Days of experiment) of selected parameters are shown in Figs. 4.1 to 4.6.

Table 4.1 Average wastewater characteristics during the experimental period for influent and effluent of free pond and hyacinth pond.

Parameter	Free pond		Hyacinth pond	
	Influent	Effluent	Influent	Effluent
COD (total) mg/L	101.30	104.20	106.50	29.10
SS mg/L	51.40	59.00	53.70	13.50
TS mg/L	713.20	724.00	728.00	617.00
TKN mg/L	10.40	7.44	10.38	3.12
TP mg/L	01.46	1.54	1.48	0.47
Temp oc	29.00	28.00	28.00	24.00
pH	07.60	8.40	7.70	7.30
Detention time, d	13		13	
Flow rate L/S	5.55	4.31	5.35	4.26

The data obtained from analysis were processed statistically. Mean values for each parameter are summarized in Table 4.1.

From the effluent result it is obvious that the hyacinth pond is superior in removing the pollutants from the wastewater. Following discussion includes an explanation on the effluent quality of the free pond and the hyacinth pond.

4.2 Factors affecting the effluent concentration in pond systems

Various factors affect the observed effluent quality. The major factors affecting the effluent quality are as follows:

(1) Hydraulic regime

(2) Influent Variables (with respect to pond size, loading)

- Flow rate
- BOD/COD
- SS

4.2.1 Hydraulic Regime

Plug flow system is desirable. Dead spaces should be avoided to exploit the system's capacity. ORTH et al. (1985) reported that plug flow system can be recommended for a number of reasons:

(1) Flow should be clearly directed and dead space should be avoided for the complete exploitation of the system's treatment capacity.

(2) Sediments should be easy to locate.

(3) A straight forward development of bioconversion process should be favoured and a succession of bio-communities should develop to the benefit of the overall treatment efficiency.

4.2.2 Influent variables

The fluctuating nature of variable in the influent affects the effluent quality of the system. Among the variables that affect the effluent quality are BOD or COD and SS. Variation in organic concentration can not be controlled. So variation in waste characteristics, including organic concentration and flow may affect the effluent quality directly. An increase in flow rate will decrease the detention time and increase the pollutant load in the system. This condition creates turbulance in the system and increased flowrate and overflow rate over the effluent weir. From Figs. 4.1 to 4.5, the step change variation in the effluent change concentration may be due to the change in influent concentration.

4.3 Discussion

Comparing the treatment efficiency of the system with and without hyacinths, the hyacinth pond system appeared better in treating the domestic wastewater of AIT campus. When the water hyacinth coverage reached nearly 80 % (measured as % area of pond) the effluent from the system was ussually clear. The effluent from the free pond was turbid and green in color with suspended algae. Mean dissolved oxygen in the effluent of the free pond and the hyacinth pond was 3.7 and 0.9 respectively (measured during the observation period). Roots of water hyacinth plants were short which is explained by high nutrient availability (GOPAL and SHARMA, 1981). Density of water hyacinths per square meter was higher at the influent side than in the effluent side and was measured as 35 number per square meter (23 kg/m2) and 46 number per square meter (18 kg/m2) respectively.

DO in the hyacinth pond effluent never increased as much as the DO in the free pond. Figure 4.6 shows the DO level at the free pond and hyacinth pond effluent. It is obvious that the DO level measured at any particular time was always higher for free pond effluent than for the water hyacinth pond effluent. Even with 20 % coverage, the difference in DO level for free pond and hyacinth pond was considerable. The maximum value of DO level in hyacinth pond reached 2.1 mg/L and the minimum value was 0.3 mg/L. Gap in the middle portion of Fig. 4.6 indicates the time when DO was not measured due to equipment damage. Roots of water hyacinths were black in colour indicating that some sulphide gas might have evolved from the sediments.

4.3.1 Total Solids

It was observed that total solids (TS) removal was not significant in both ponds. In the free pond mean TS concentration in the effluent was higher than in the influent and also the coefficient of variation for the effluent was higher than for the influent indicating that higher degree of dispersion takes place in pond. From the statistical analysis, coefficient of variation for influent concentration was 16% and for effluent concentration,it was 18% for the freeond (Table 4.4).

Mean effluent TS concentration (during experimental period from 27 October 1986 to 22 January 1987) were, 724 and 617 mg/L for the the pond and the hyacinth pond respectively. For the hyacinth pond, In case of hyacinth , coefficient of variation in effluent (8%) was lower than in influent (18%) indicating that the influent concentration may be decisive for the variation of concentration in the effluent. Fig.4.7 shows the smoothened effluent concentration (3 weeks average) of TS for the hyacinth pond and the free pond. It is obvious that effluent concentrations of of the hyacinth pond (Fig.4.7) were always lower than that of the free pond

4.3.2 Suspended solids

The concentration of suspended solids was tremendously lower in the hyacinth pond effluent. As the hyacinth plant coverage increased, the removal efficiency also increased in hyacinth pond where as suspended solids in the effluent in the free pond (59 mg/L) remained above the mean influent concentration (51 mg/L). Here, also the coefficient of variation

of the effluent concentrations was is higher than for the influent which indicates that the suspended solid concentration in the influent has no impact in the effluent concentration variation. This is because of the algae production in the oxidation pond and subsequent release of algae in the effluent. But in case of the hyacinth pond algae growth is completely prevented by means of simple physical phenomenon, the shading by hyacinth plant. The extreme fluctuation seen in the Fig. 4.2 may also be attributed to human disturbance caused by people moving around. The normal fluctuation is due to the fluctuating growth of algae in the oxidation pond. Fig. 4.2 shows the variation of SS concentration at different days of experiment for the free pond and the hyacinth pond system. The clear nature of plot shows that the hyacinth pond system had lower ~~effluent~~ effluent concentration than the free pond system. SS decreased tremendously in the hyacinth pond, reaching as much as 5 mg/L, where as in free pond the corresponding effluent concentration appeared as high as 52 mg/L (Appendix A). It is more clear from the Fig. 4.8 that the hyacinth pond system is efficient in producing lower values of effluent concentrations than the free pond system. Table 4.2 shows the statistically smoothened effluent concentration (3 weeks average) for the free pond and the hyacinth pond system. The variaton of effluent concentration (smoothened) ranges from 43 mg/L to 78 mg/L for the free pond and 9 mg/L to 20 mg/L for the hyacinth pond (Table 4.2). The effluent concentration of SS in the hyacinth pond for 100 % coverage was 9.0 mg/L and at corresponding date of observation, the effluent concentration in free pond was 45 mg/L.

Mean values and coefficient of variation of parameters are tabulated in Table 4.4 . Mean values of SS for the free pond and hyacinth pond are 59 mg/L and 13.5 mg/L respectively and the respective coefficients of variation are 38 % and 65 %. Assuming the effluent standard for SS to be 30 mg/L, the normalised mean (mean effluent SS concentration in mg/L)/(effluent standard in mg/L) for the free pond and the hyacinth pond will be 1.96 and .22 respectively. With the help of Fig. 4.13 and Table 4.5, the reliability of obtaining lower concentrations than the effluent standard is given by 6.5 % for the free pond system and more than 95 % for the hyacinth pond system.

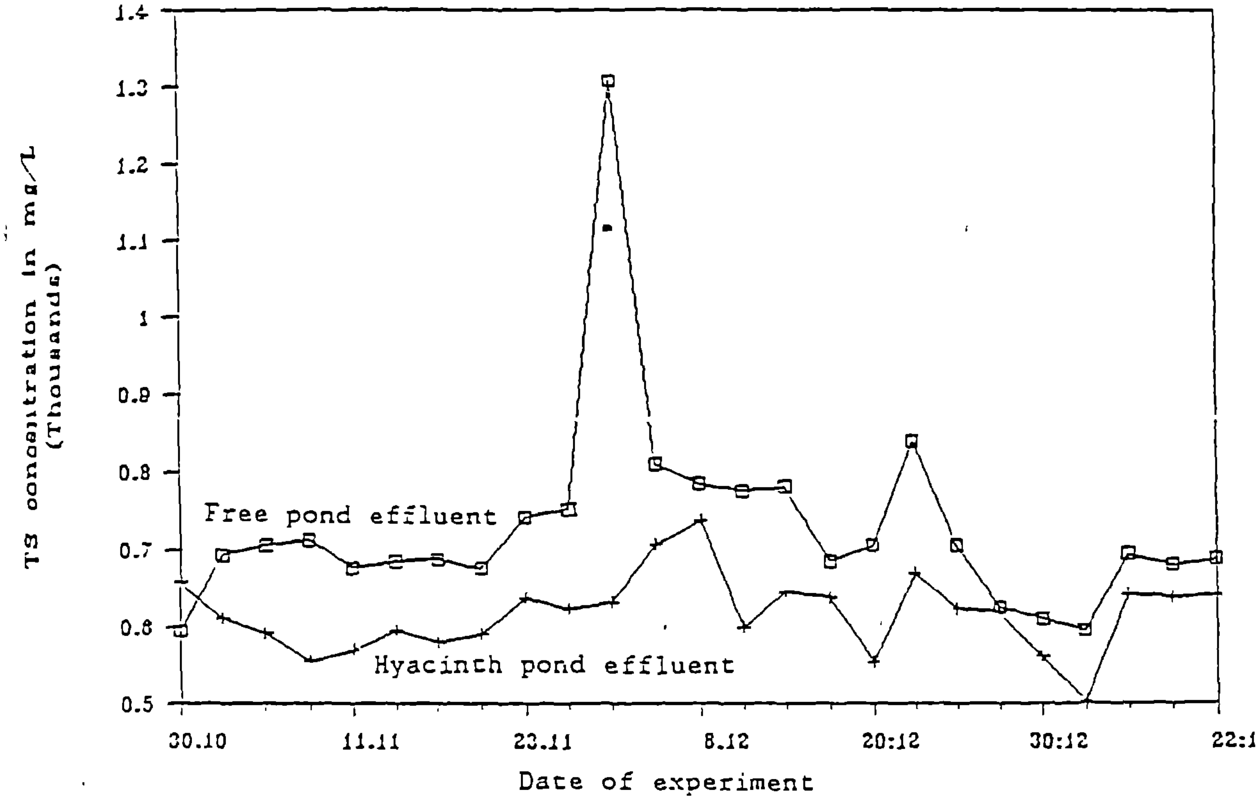

Fig.4.1 Variation of effluent TS concentration

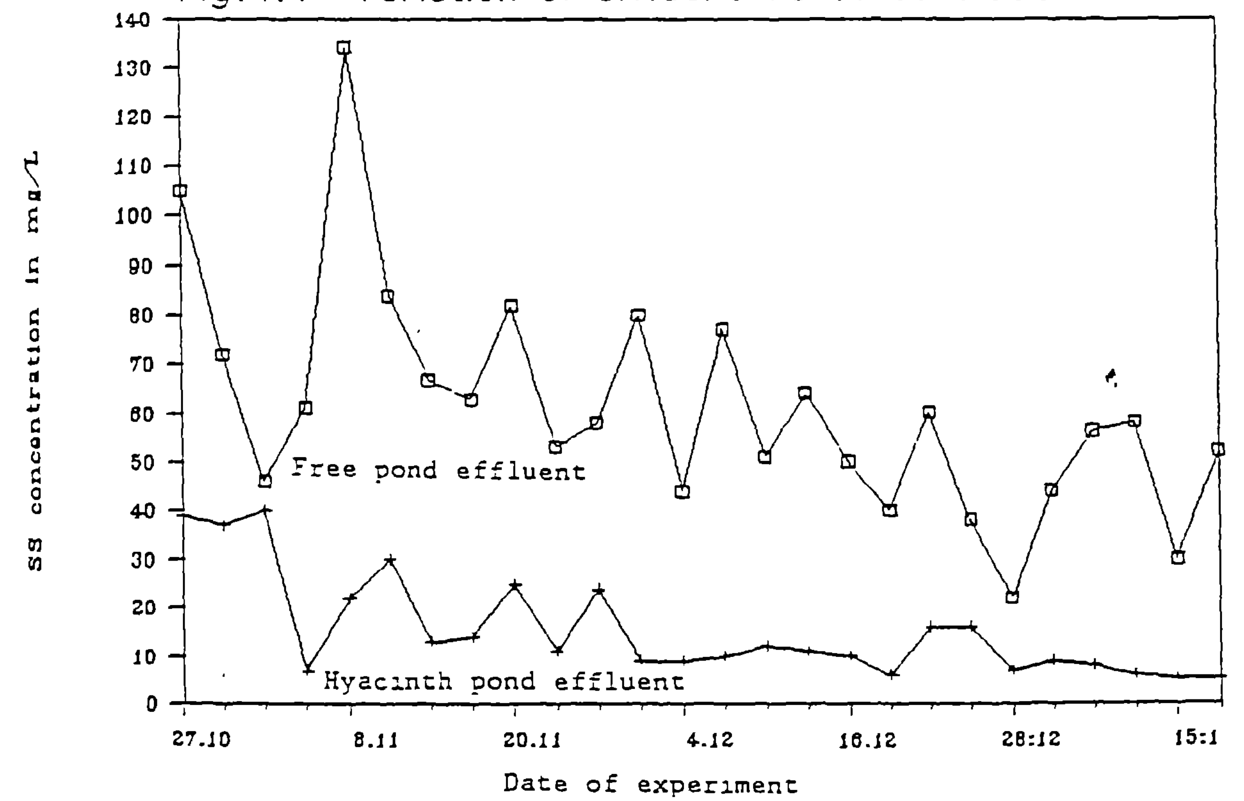

Fig.4.2 Variation of effluent SS concentration

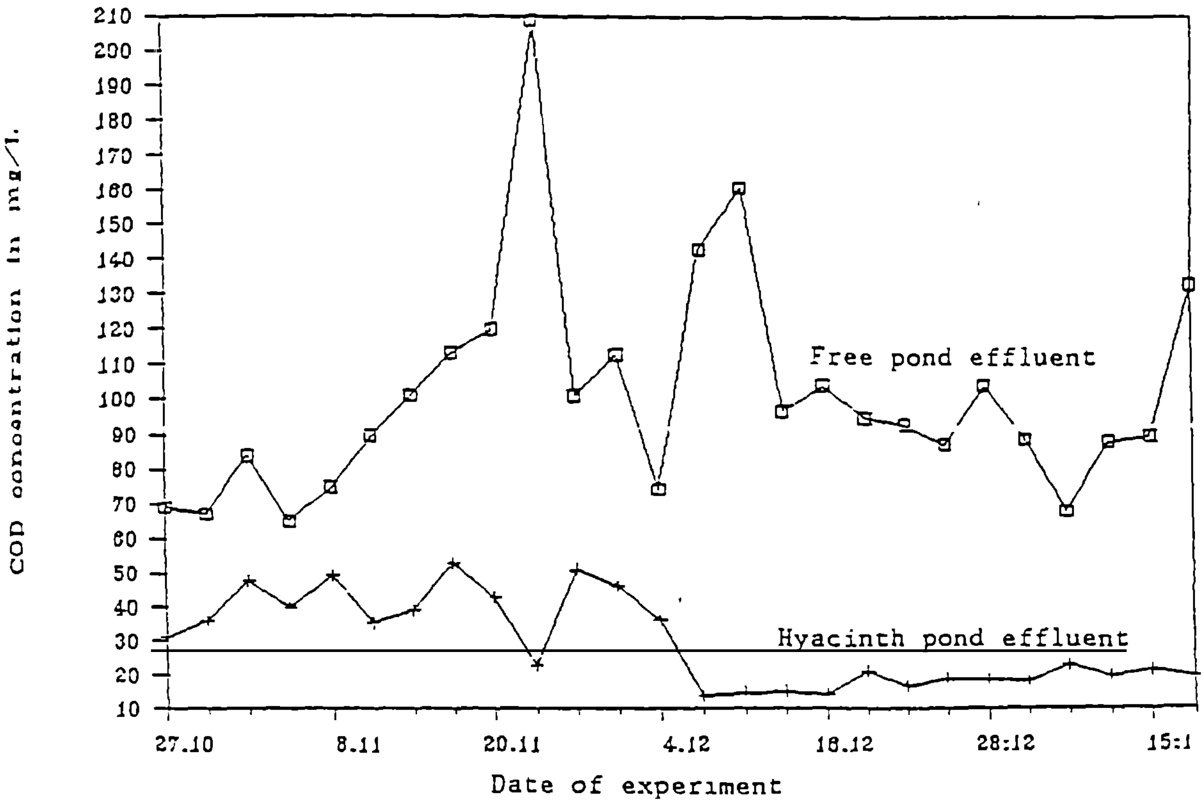

Fig.4.3 Variation of effluent COD concentration

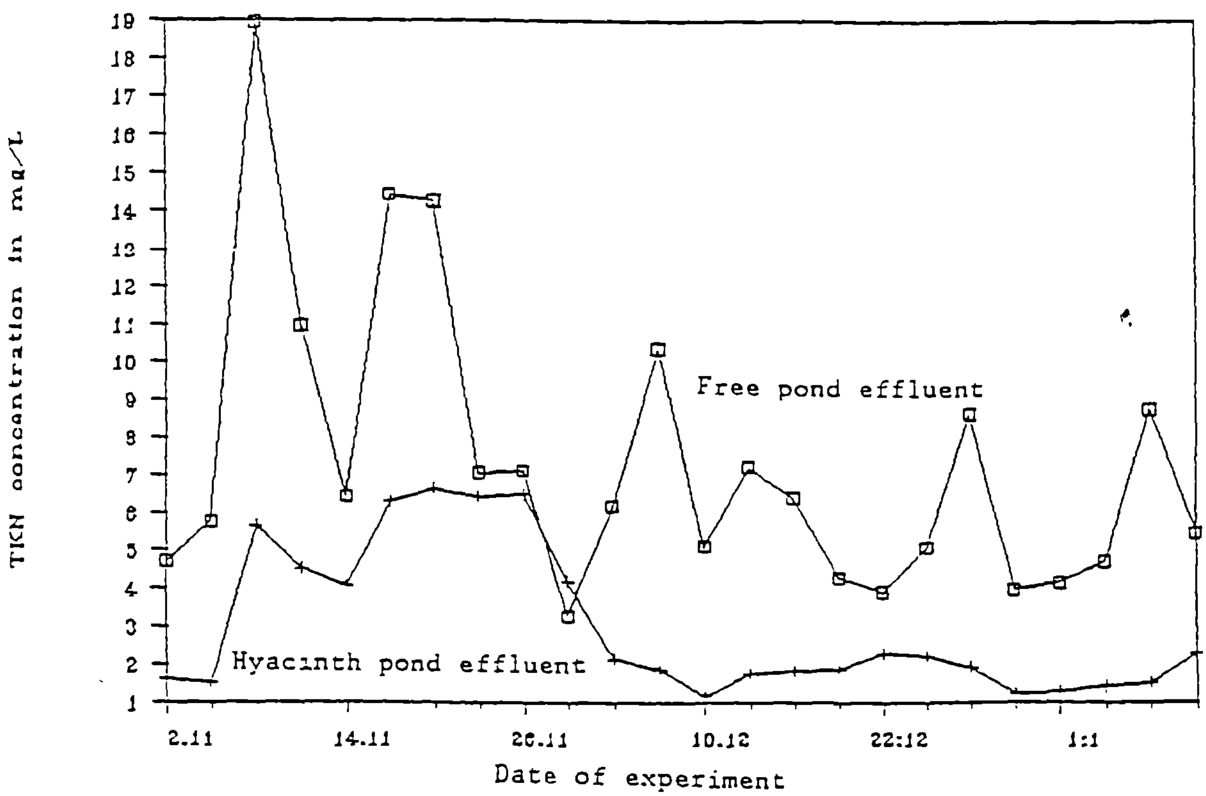

Fig.4.4 Variation of effluent TKN concentration

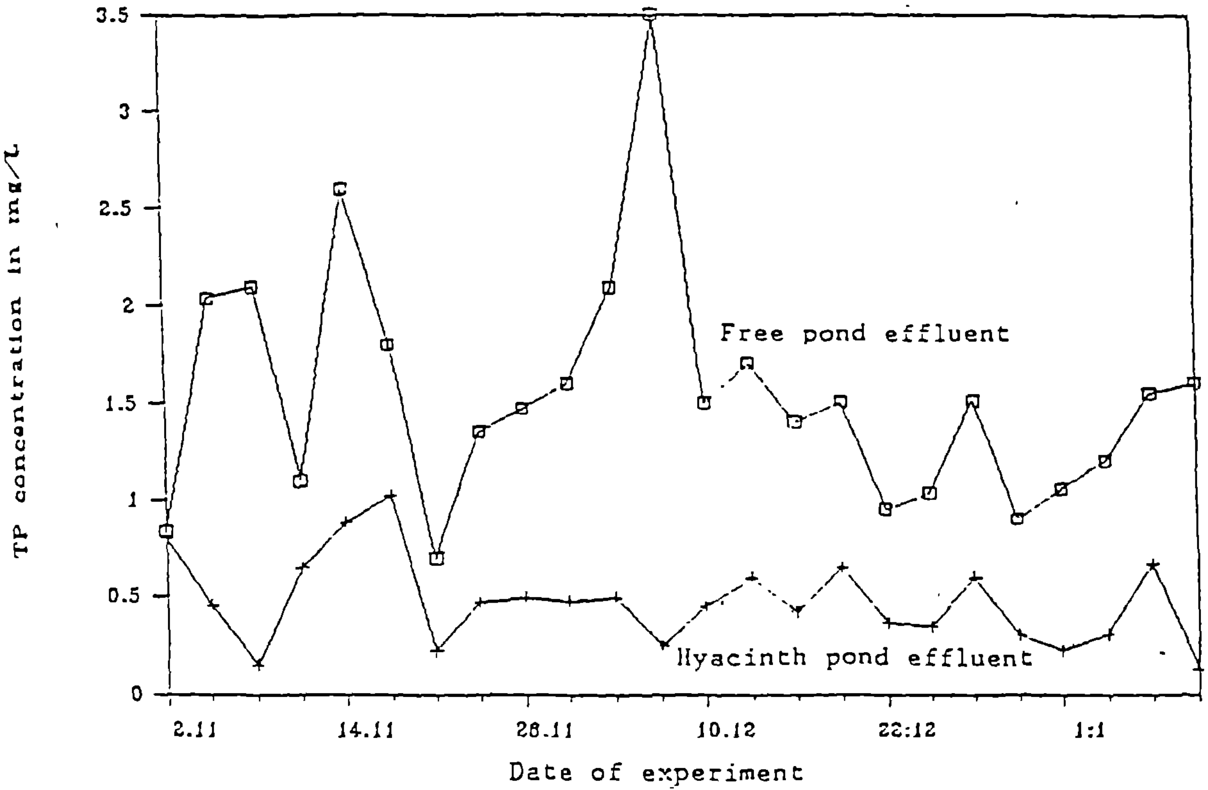

Fig.4.5 Variation of effluent TP concentration

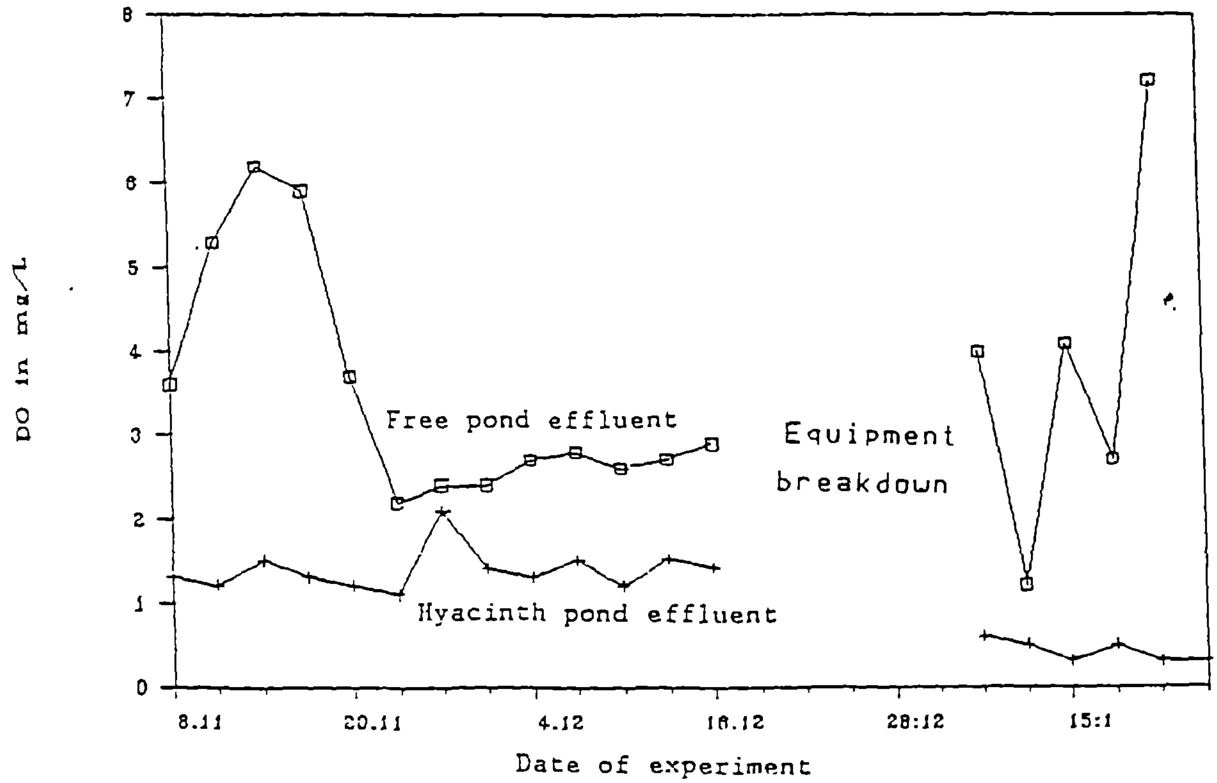

Fig.4.6 Variation of effluent DO concentration

4.3.3 Chemical Oxygen Demand (COD)

In COD removal the free pond acted completely inefficient in removing the pollutants. Mostly water quality standards do not differentiate between suspended solids and algae, because of the fact that algae produced in an oxidation pond are discharged into the recieving water bodies resulting in oxygen consumption as algae die. Hence, algae production is most undesirable feature of the the treatment system, when the effluent is to be discharged to receiving water bodies. COD variation in the effluent of free pond is attributed to the production of algae which is organic matter and requires oxygen for its degradation. Fig. 4.3 shows the variation of effluent COD concentrations for the free pond and the hyacinth pond at different date of observation. It appeared from the Fig. 4.3 that the effluent concentrations in the hyacinth pond were considerably lower than the effluent concentrations in the free pond. Mean effluent concentrations (during the period of observation) in the free pond and the hyacinth pond were 104.2 mg/L and 29.0 mg/L respectively (Table 4.1). For 100 % hyacinth cover the effluent concentration for the free pond and the hyacinth pond were 94.00 mg/L and 20 mg/L respectively (Table 4.2).

Fig. 4.8 shows the clear trend of effluent concentrations for the free pond and the hyacinth pond with different days of observation. Statistically smoothened values of effluent concentrations (3 weeks average) represented in Fig. 4.8 show that the hyacinth pond is superior in producing better quality of effluent than the free pond system.

Assuming the effluent standard of COD (total) to be 60 mg/L, the reliability of the systems in producing the effluent concentration lower than the effluent standard is compared as follows. From Table 4.4 coefficient of variation of effluent COD (total) concentration for the free pond and the hyacinth pond are 31 % and 47 %. As can be seen Table 4.1 that the mean value of the observed COD effluent concentrations for the free pond and the hyacinth were 104.20 mg/L and 29 mg/L respectively. So the normalised mean (mean effluent concentration in mg/L)/(effluent standard in mg/L) would 1.73 and 0.48 respectively. With the help of Fig.4.13, reliability of obtaining lower concentrations than the effluent standard for the above mentioned coefficient of variation will be more than 95 % for the hyacinth pond and only 6 % for the free pond.

4.3.4 Total Kjeldahl nitrogen

Hyacinth pond system was more efficient in removing total nitrogen than the free pond system. Mean effluent concentrations for the free pond and the hyacinth pond were 7.44 mg/L and 3.12 mg/L respectively (Table 4.1). Effluent TKN concentration for 100 % hyacinth coverage for the free pond and the hyacinth pond were 5.60 mg/L and 2.0 mg/L respectively(Table 4.2). The result obtained for nitrogen removal are quite promising for the hyacinth pond as compared to the free pond system. The effluent concentrations for the free pond and the hyacinth pond at different dates of experiment are shown in Fig. 4.4. Beginning effluent concentration varied significantly as is seen in Fig. 4.4 . The variation may be attributed to the variation in the influent concentration (refer to Appendix A).

Statistically smoothened values of effluent TKN concentrations for the hyacinth pond and the free pond are shown in Fig.4.9. It clearly shows that better quality of effluent was obtained for the hyacinth pond than the free pond.

From the current state of knowledge nitrogen is removed from wastewater during aquatic treatment by number of mechanism: (1) volatilization of ammonia, (2) bacterial nitrification /denitrification, and (3) uptake by plants and subsquent harvesting.Higher pH are favorable for ammonia volatilization. In the hyacinth pond usually lower pH were, obtained than in the free pond. Table 4.1 shows the average pH for the hyacinth and free pond effluent as 8.4 and 7.3 respectively. With the increase in hyacinth coverage, the decrease in effluent concentration was not significant as compared to the free pond. So nitrification and denitrification are likely to be the main mechanism for the removal of nitrogen.

Assuming the effluent standard for TKN to be 5 mg/L .(for secondry advanced treatment) the reliability of obtaining lower effluent concentrations than the effluent standard is calculated as follws.

The mean value of effluent concentrations in the free pond and hyacinth pond are 7.44 and 3.12 mg/L with coefficients of variation 52 and 61 % respectively (Table 4.4). The normalised mean for the hyacinth and the free pond are 0.62 and 1.5 respectively. With the help of Fig. 4.13 and Table 4.5, the reliability of obtaining lower concentrations than the effluent standard are seen as 90 % and 28 % respectively, for the hyacinth pond and the free pond effluents.

4.3.5 Total Phosphorus (as phosphate)

Mean effluent concentration for the free pond and hyacinth pond were 1.54 mg/L and 0.47mg/L (Table 4.1) respectively. The effluent concentration of the free pond was higher than the influent concentration, whereas in hyacinth pond TP decreased from 1.48 mg/L to 0.47 mg/L. The effluent concentrations at different days of experiment are shown in Fig. 4.5. Statistically smoothened values of effluent concentrations are plotted in Fig. 4.9 which shows the clear difference between the effluent concentrations for the two systems. The decrease in effluent concentration is not significant for the increasing coverage of hyacinth which justifies the idea that plant coverage has no significant effect on phosphorus removal. The phosphorus removal was better for the hyacinth pond as compared to the the free pond system. The actual cause of removal was not known.

As in the previous cases the reliability of the system of (refer Table 4.5 and Fig. 4.13) to produce lower effluent concentrations than the effluent standard of 1 mg/L(for advanced waste treatment system) were nearly 95 % and 11 % respectively for the hyacinth pond and the free pond respectively. For the coefficients of variation and means of the hyacinth pond and the free pond effluent Table 4.4 was refered.

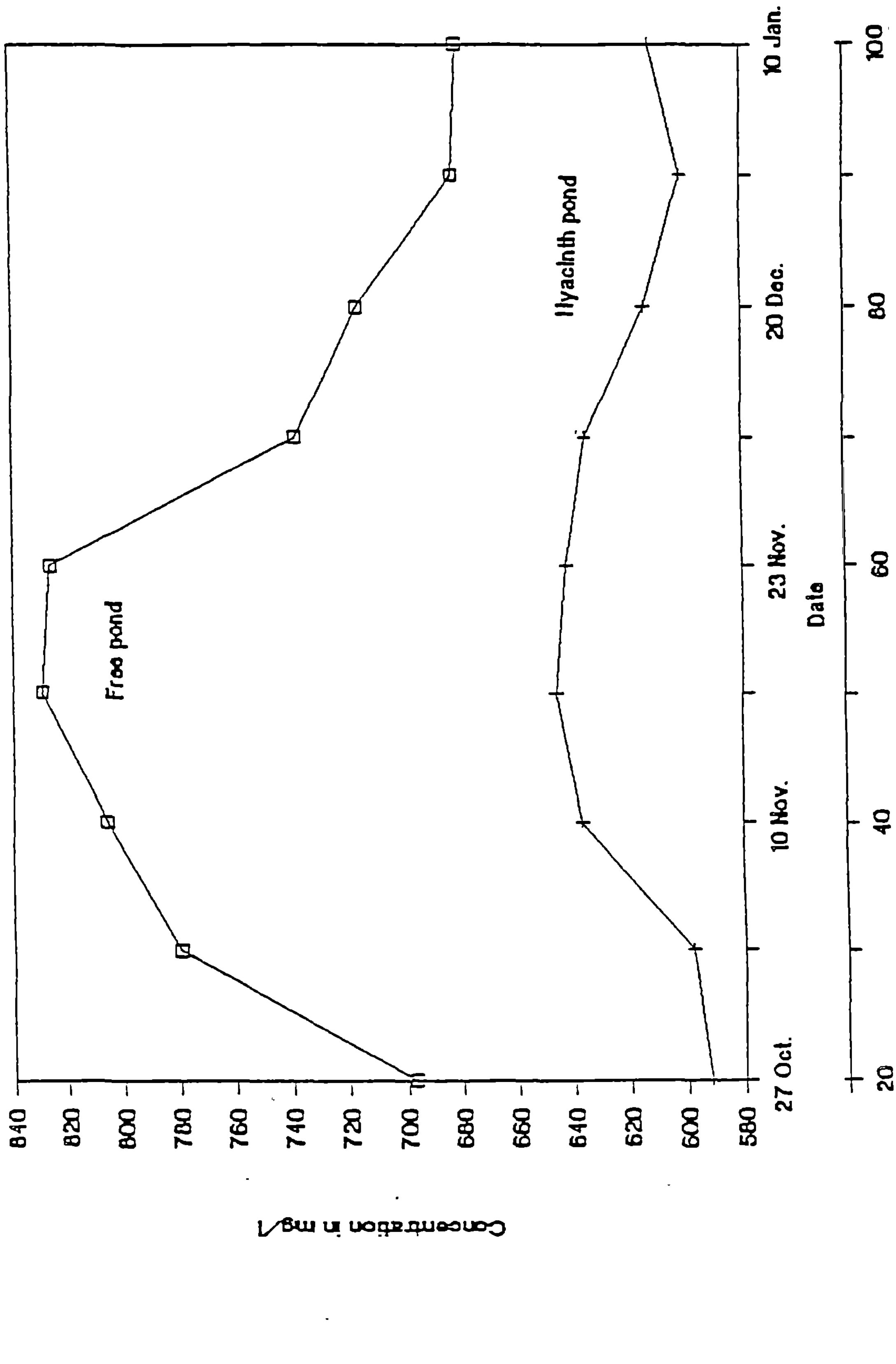

Fig.4.7 Effluent TS concentration (3 wks' avg)

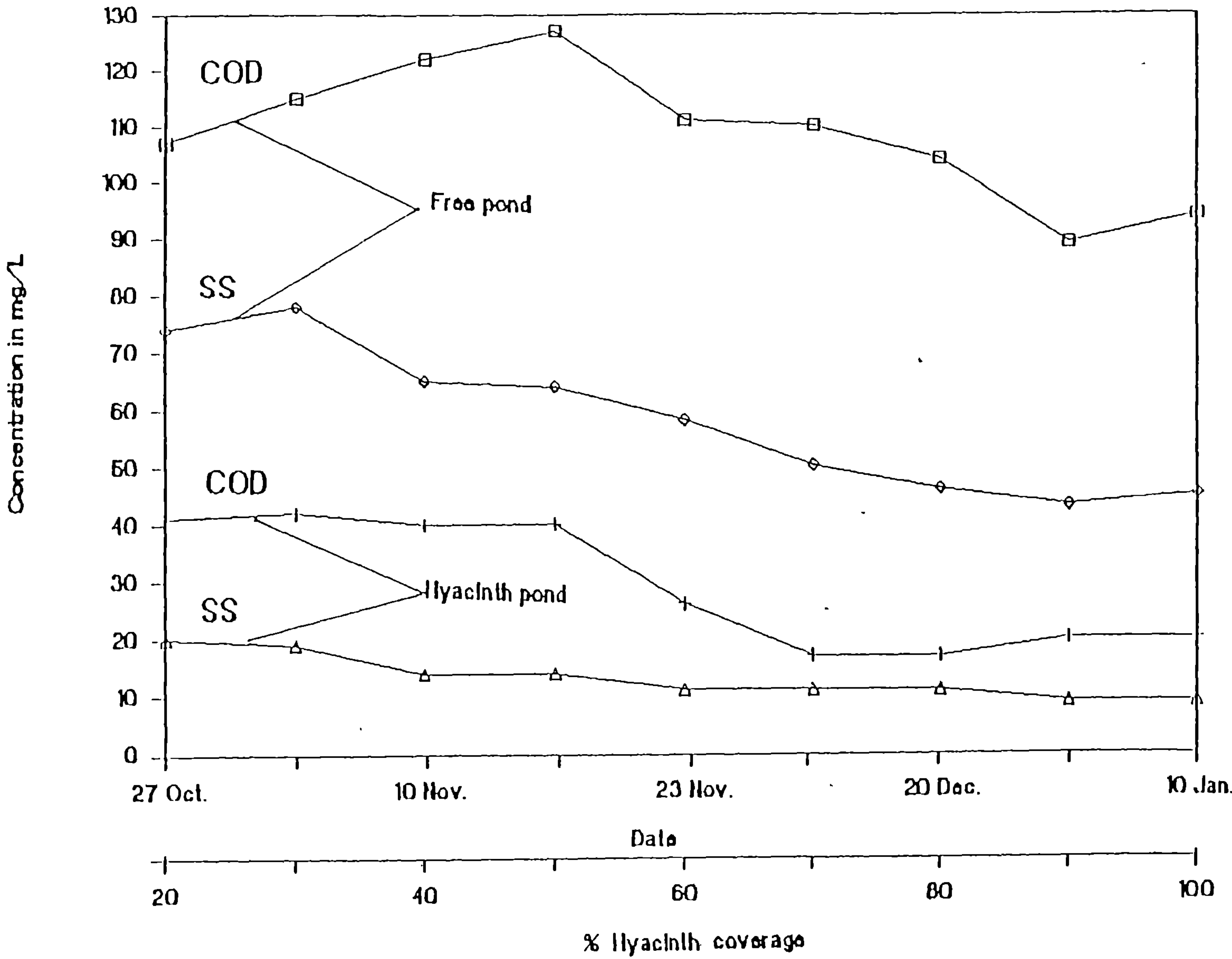

Fig.4.8 Effluent SS and COD concentration (3 wks' avg)

Table 4.2 Effluent concentration at different water hyacinth coverage (3 weeks' average), mg/L.

%cover of WH	TSfp	TShp	SSfp	SShp	CODfp	CODhp	TKNfp	TKNhp	TPfp	TPh
20	697	592	74	20	107	41	10.4	4.6	1.6	0.6
30	780	598	78	19	115	42	10.3	5.6	1.6	0.54
40	806	637	65	14	122	40	8.7	4.8	1.9	0.50
50	829	646	64	14	127	40	7.6	4.8	1.7	0.54
60	826	642	58	11	111	26	6.3	2.7	1.8	0.50
70	738	635	50	11	110	17	6.5	1.9	1.6	0.45
80	716	614	46	11	104	17	5.6	1.8	1.3	0.46
90	682	601	43	9	89	20	5.5	1.9	1.2	0.43
100	680	612	45	9	94	20	5.6	2.0	1.2	0.36

WH - water hyacinth, fp - free pond, hp - hyacinth pond

Table 4.3 Removal (%) efficiency at different coverage of water hyacinth (3 weeks' average)

%cover of WH	TSfp	TShp	SSfp	SShp	CODfp	CODhp	TKNfp	TKNhp	TPfp	TPh
20	-0.0	14.9	-48.0	58.3	4.4	59.9	19.5	65.6	-18.1	59.1
30	-0.5	21.6	-5.0	67.6	-8.5	62.5	22.5	60.5	14.3	61.7
40	-2.2	16.3	-2.2	75.8	-8.5	68.3	31.4	60.8	-9.2	65.1
50	0.6	17.4	-0.6	75.4	-17.9	74.0	32.8	64.4	0.6	72.9
60	-0.1	18.7	-0.1	80.9	-1.8	77.2	40.3	72.7	0.5	70.5
70	0.9	10.2	0.0	80.1	-15.5	84.8	28.2	78.7	-8.6	69.0
80	-1.4	13.1	8.0	78.7	-10.0	83.0	30.0	77.0	7.0	68.5
90	0.5	10.2	13.9	82.5	3.0	80.3	29.0	75.0	-8.0	67.0
100	-4.0	9.8	10.0	83.0	-2.0	80.6	28.0	74.0	-0.8	73.0

WH - Water Hyacinth, fp - free pond, hp - hyacinth pond

4.4 Statistical Analysis of the Result in Full Scale Experiment

Data were processed statistically. The distribution characteristics of each variable was determined and respective distribution of variables is shown in Table 4.4.

Table 4.4 : Normal and lognormal distribution tests for the parameters at 95% confidence level (C.L.)

Parameter Tested	Mean	Coefficient of variation (%)	Distribution filted at 95%C.L
TSfi	713.2	16	N, LN
TSfe	724.0	18	None
TShi	728.0	18	N, LN
TShe	617.0	8	N
SSfi	51.4	33	N, LN
SSfe	59.0	38	N, LN
SShi	53.7	33	N, LN
SShe	13.5	65	LN
CODfi	101.3	16	N, LN
CODfe	104.2	31	N, LN
CODhi	106.5	20	N
CODhe	29.0	47	LN
TKNfi	10.4	31	N, LN
TKNfe	7.4	52	LN
TKNhi	10.38	35	N, LN
TKNhe	3.12	61	LN
TPfi	1.46	38	N, LN
TPfe	1.54	40	N, LN
TPhi	1.48	28	N, LN
TPhe	1.47	48	N, LN

TS = Total Solid Concentration
SS = Suspended Solid Concentration
COD = Chemical Oxygen Demand
TKN = Total Kjeldahl Nitrogen
TP = Total Phosphate
fi = Free pond influent
hi = hyacinth pond influent
fe = free pond effluent
he = haycinth pond effluent
LN = Lognormal
N = Normal

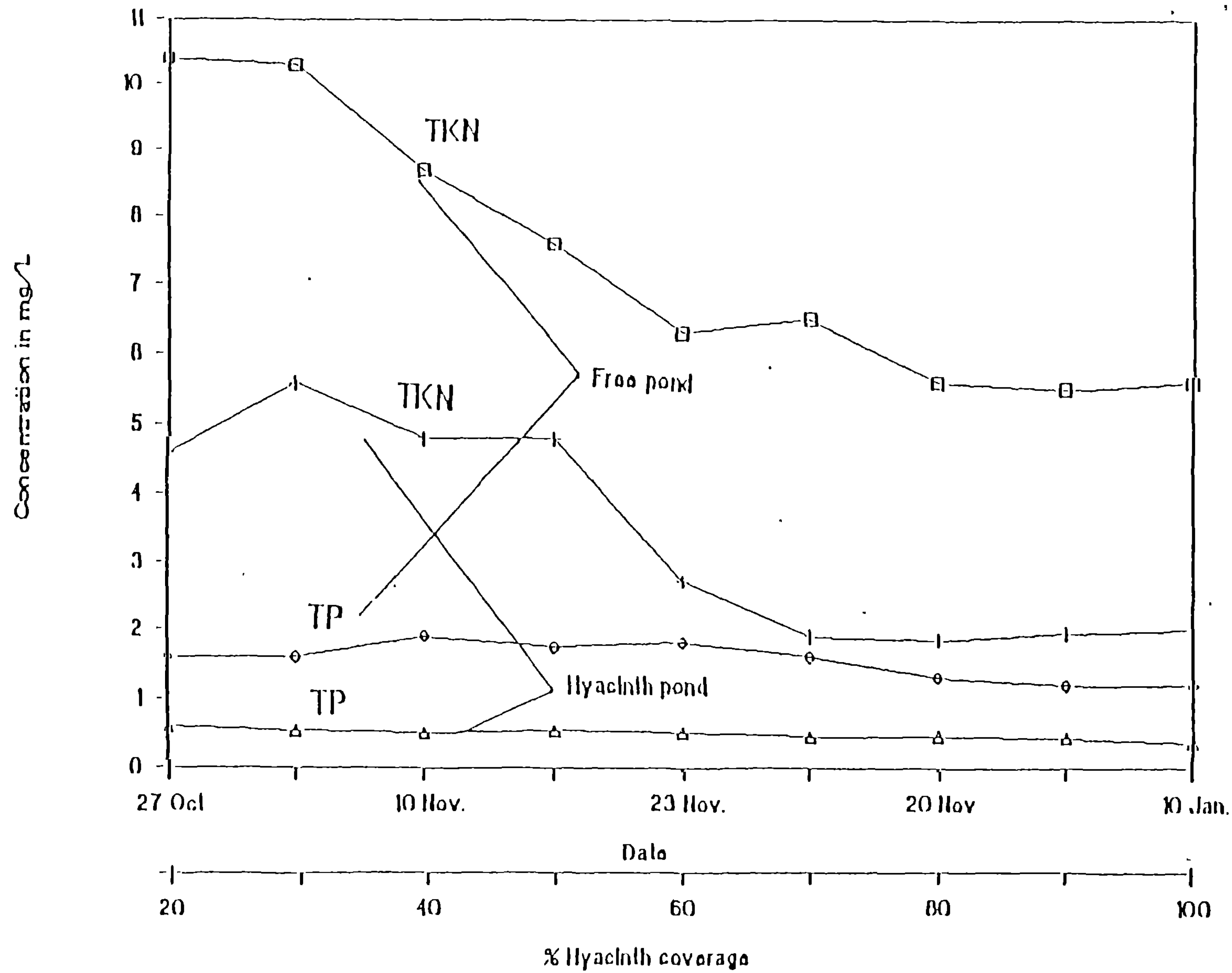

Fig.4.9 Effluent TKN and TP concentration (3 wks' avg)

4.5 Removal efficiency of the Systems

The effluent concentrations for free pond and hyacinth pond (3 weeks' average) is tabulated in Table 4.2. The percent removal in terms of concentration (3 weeks'average) is tabulated in Table 4.3. Fig.4.10 shows the removal efficiencies of the free pond and and hyacinth pond system in removing TS and SS. Removal of suspended solids was maximum (83 %) at 100 % hyacinth coverage for the hyacinth pond system whereas for the free pond system , there was no removal (rather the effluent concentration was higher than in the influent) in the beginning and was only 10 % at corresponding date when the hyacinth coverage was 100 %. At 6o % hyacinth coverage SS removal reached 80 % in water hyacinth pond and at corresponding date SS removal at the freepond was -0.1 (i.e. free pond produced higher concentration in the effluent than in the influent) . From the Fig 4.10 SS removal increased with the increase in hyacinth coverage.

COD removal at different coverage of hyacinth for the hyacinth pond system and at corresponding date for free pond system is shown in Fig. 4.11. COD removal increases with the increase in hyacinth coverage. At 70 % coverage removal of COD reached nearly 85 % , whereas COD removal at corresponding date for free pond was nearly -16% (Table 4.3, Fig. 4.11). This fact may be attributed to the prevention of algae growth and metabolic activities of plants and bacteria (attached to the roots of hyacinths).

The removal of nitrogen and phosphorus at different hyacinth coverage is clearly shown in Fig. 4.12.The results of removal efficiences are promising as compared to the free pond system. Maximum removal efficiency (78.7 %) was obtained at 70 % hyacinth coverage for the hyacinth pond system and at corresponding date the removal efficiency for free pond system was 28.2 %. The increase in removal efficiency for total nitrogen was not significant with the increase in hyacinth coverage, as compared to the free pond system, indicating that hyacinth coverage has no direct effect on the nitrogen removal.

Phosphorus removal in free pond was not effective rather increased in the effluent in most of the cases resulting in negative removal efficiency (Fig 4.12). TP removal in the hyacinth pond systen was effective as compared to free pond system. Removal efficiency of 73 % was obtained at 100 % coverage(Table 4.3), corresponding removal of TP in free pond system was -0.8. Even at the 60 % coverage, SS,COD,TKN and TP were removed at 80.9, 77.2 , 72.7 and 70.5 % respectively. But in free pond, SS,COD,TKN and TP were removed at -0.1,-1.8,40.2 and 0.5 % respectively. The mean removal of SS, COD,TKN and TP for free pond system were -15.7,-2.9, 28.5 and -5.47 % respectively and for the hyacinth system 74.9, 72.7, 70 and 68.2 % removal efficiences were obtained for SS, COD, TKN and TP respectively. The above removal efficiences were calculated from the mean concentration of parameters tabulated in Table 4.1.

Mean mass of the pollutants were removed at 83.3 kg/(ha.d) (78 %) 7.89 kg/(ha.d)(76 %) and 1.1kg/(ha.d) (74.8 %) for COD,TKN and TP respectively in the hyacinth pond system, whereas in free pond system COD, TKN and TP were removed at 19.8 kg/(ha.d) (20 %) , 4.5 kg/(ha.d) (44.4 %) and .26 kg/(ha.d) (18.30 %) respectively. Similarly at 100 % hyacinth

coverage, mass(calculated from three weeks' average) COD, TKN and TP were removed at 84.1 kg/(ha.d)(84 %), 6.2 kg/(ha.d) (79.6%) and 1.08 kg/(ha.d) (79.4 %) respectively. For free pond system ,COD, TKN and TP were removed at 21.5 kg/(ha.d) (24 %), 3.4 kg/(ha.d) (44.8 %) and 0.26 kg/(ha.d) (22 %) respectively.

From the result it appeared that the hyacinth pond system are superior to the free pond system. Aerobic treatment systems are seen to be faster than the anaerobic systems under the same organic loading and identical environments. Hyacinth pond was more effective than the the oxidation pond. So, aerobic degradation (with supply of oxygen by hyacinths) might have been taken place in the hyacinth pond with anaerobic degradation in the sediments which makes the hyacinth system more effective.

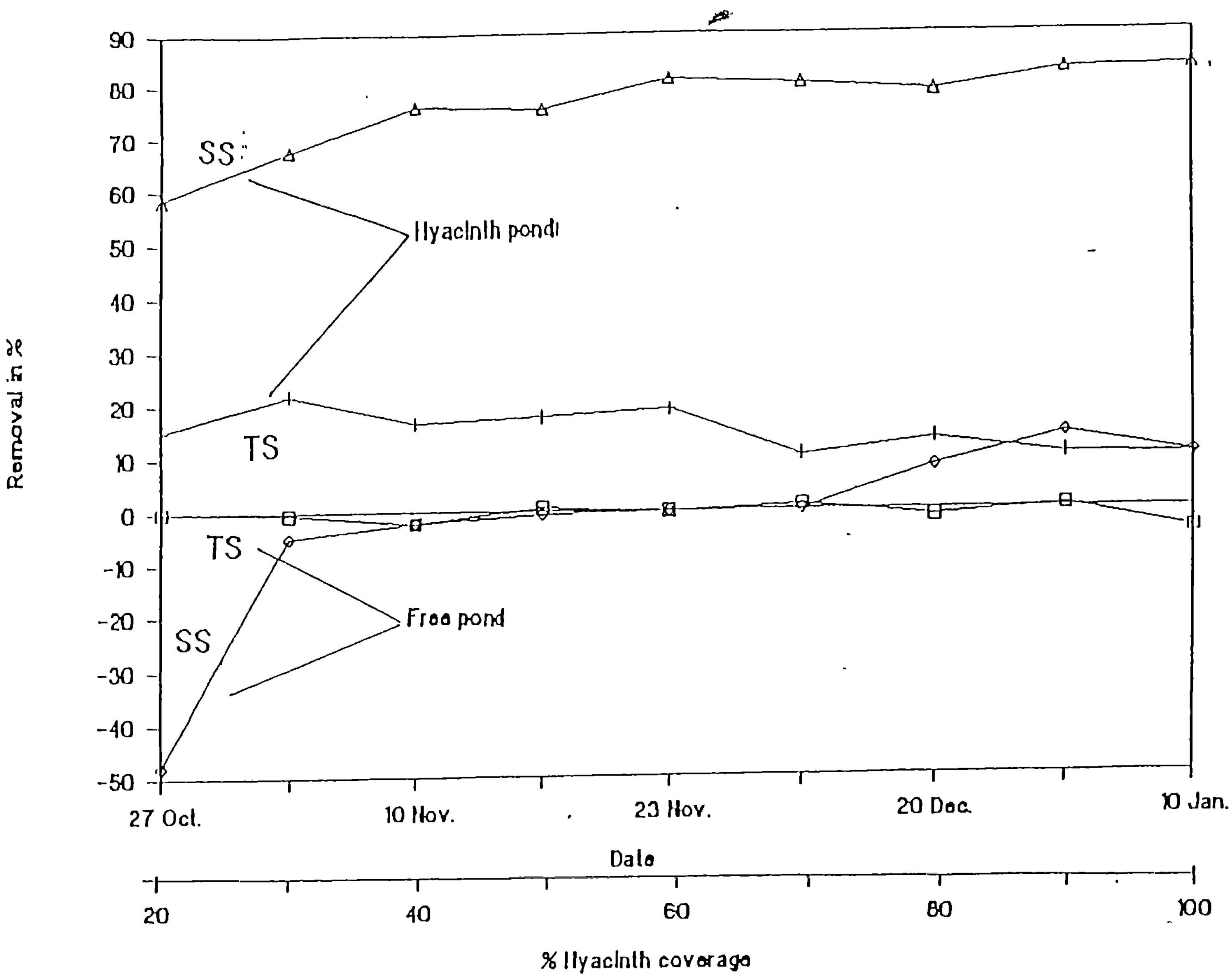

Fig.4.10 TS and SS removal (3 wks' avg)

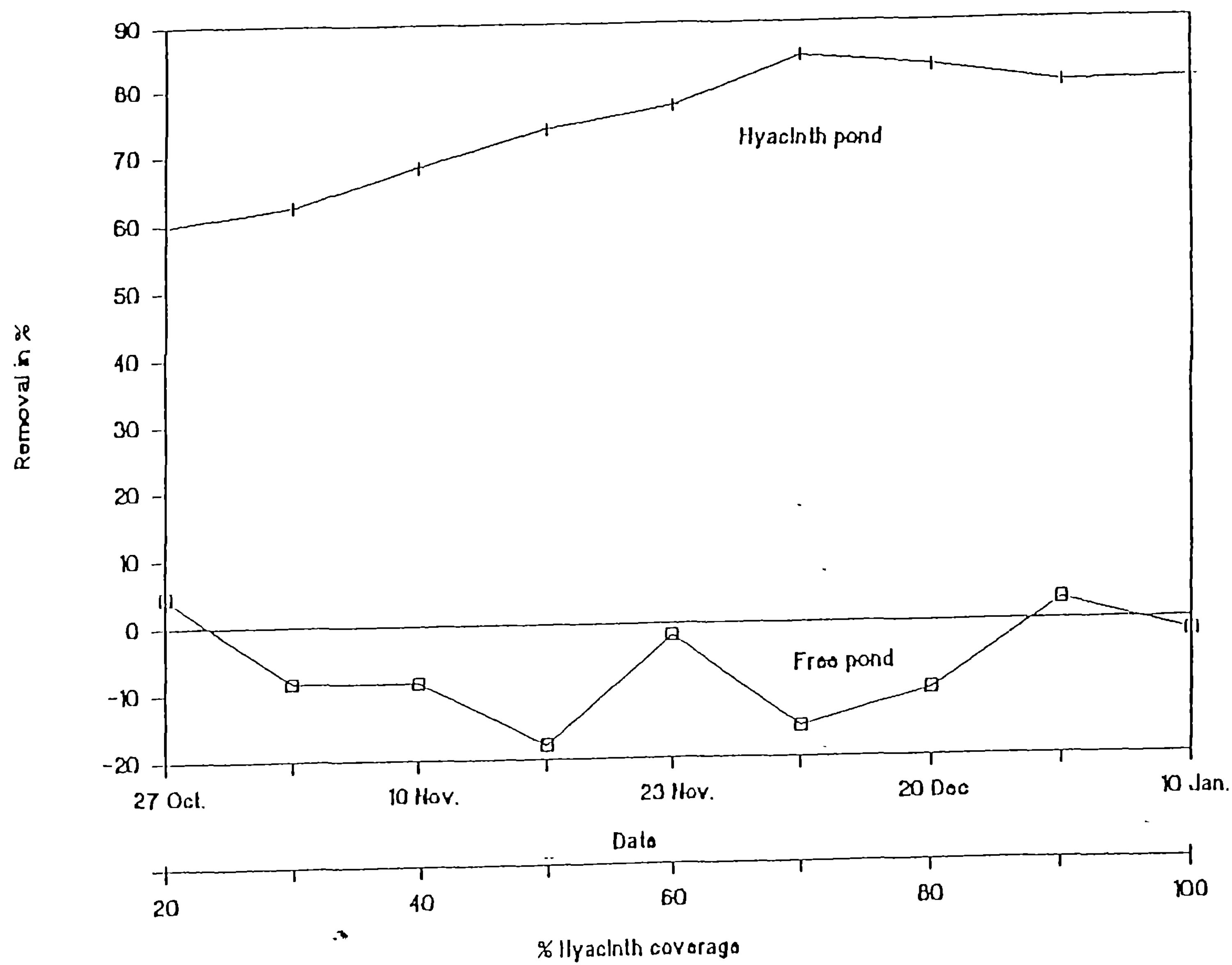

Fig.4.11 COD removal (3 wks' avg)

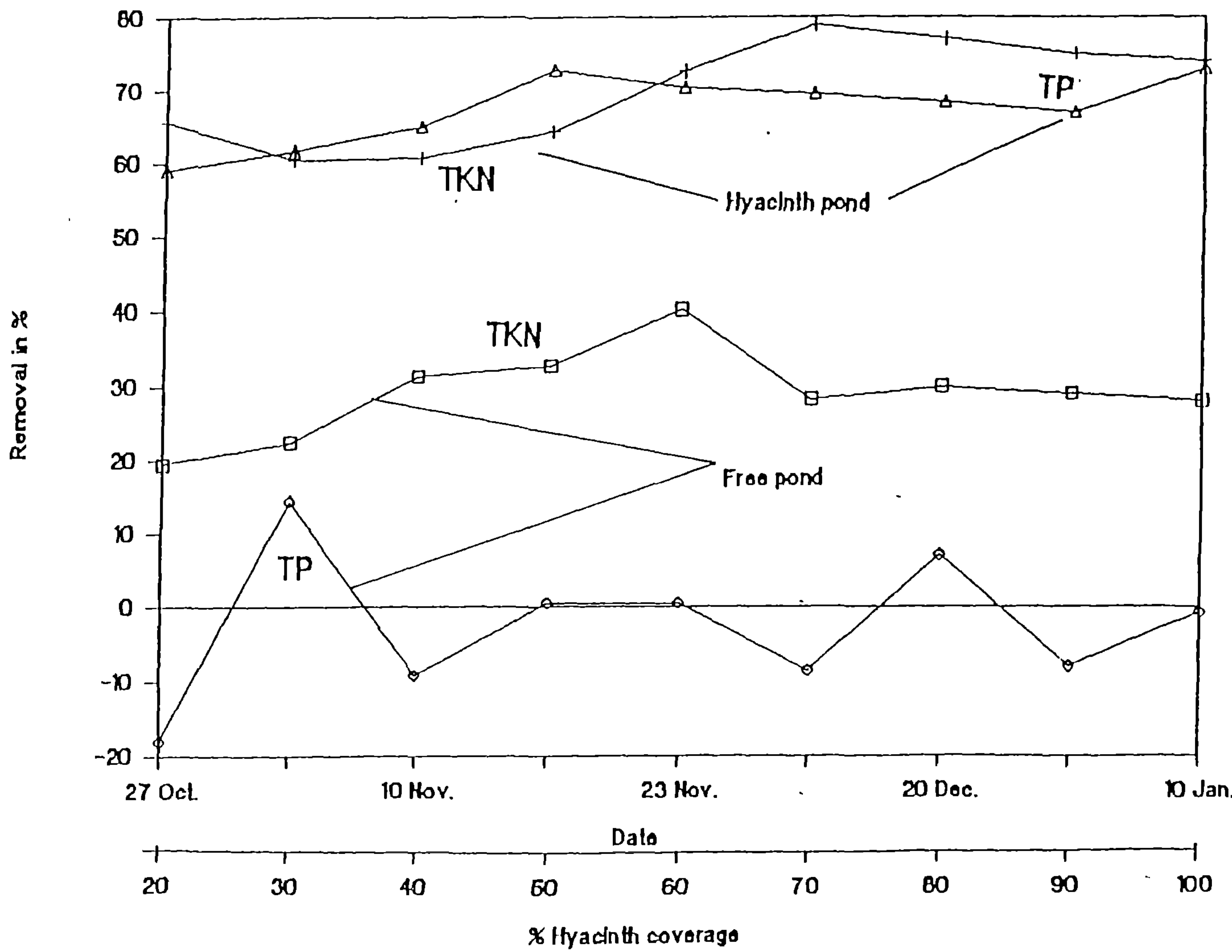

Fig.4.12 TKN and TP removal (3 wks' avg)

Table 4.5 Reliability as a function of normalised mean and Vx of effluent concentration.

m_x/X_s \ V_x	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.25	1.5	2.0
0.3	>0.9999	>0.9999	>0.9999	0.9995	0.9939	0.9706	0.9134	0.8179	0.6932	0.5583	0.2698	0.1083	0.0136
0.4	>0.9999	>0.9999	0.9995	0.9950	0.9767	0.9353	0.8681	0.7799	0.6793	0.5763	0.3507	0.1950	0.0542
0.5	>0.9999	>0.9999	0.9973	0.9852	0.9557	0.9062	0.8391	0.7607	0.6770	0.5934	0.4064	0.2669	0.1093
0.6	>0.9999	0.9993	0.9928	0.9732	0.9366	0.8840	0.8212	0.7516	0.6798	0.6092	0.4502	0.3251	0.1660
0.7	>0.9999	0.9979	0.9869	0.9610	0.9212	0.8675	0.8107	0.7483	0.6853	0.6239	0.4850	0.3721	0.2171
0.8	>0.9999	0.9959	0.9805	0.9509	0.9087	0.8594	0.8047	0.7482	0.6920	0.6373	0.5137	0.4110	0.2632
0.9	0.9996	0.9932	0.9743	0.9423	0.9006	0.8527	0.8018	0.7539	0.6992	0.6499	0.5380	0.4439	0.3033
1.0	0.9993	0.9905	0.9688	0.9353	0.8941	0.8485	0.8009	0.7530	0.7065	0.6614	0.5589	0.4718	0.3398
1.2	0.9982	0.9851	0.9597	0.9254	0.8860	0.8445	0.8023	0.7604	0.7201	0.6816	0.5936	0.4828	0.3967
1.5	0.9961	0.9785	0.9507	0.9172	0.8812	0.8446	0.7754	0.7728	0.7389	0.7075	0.5612	0.5675	0.4620

Source: NIKU et al.,(1979)

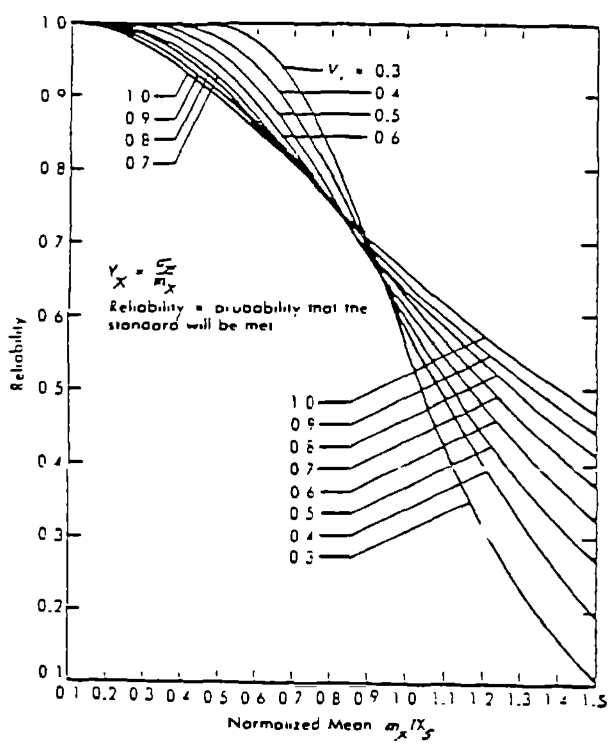

Fig.4.13 Reliability versus normalised mean for different coefficient of variations.
(Source: NIKU et al.,(1979))

4.6 Comparison of treatment efficiency of pond systems with water hyacinth, salvinia and water Lily

Laboratory scale experiments were performed in the concrete tank situated near the Regional Experiment Centre within AIT Campus Plants were put on the pond on 19th October 1986. Experiments were performed for two loadings, 41 kg/ha.d and 86 kg COD/ha.d and the responses of the system was measured. After 21 days of operation salvinia (Auriculata) started dying and algae appeared at some part of the salvinia pond. On 19th November new salvinia plant was kept on 1/3 rd of pond area. Though, the plants were dying and settled at the bottom, the removal efficiency of salvinia plant was better than the water lily pond. After keeping new salvinia plants, it was observed that the tendency of plants dying still continued. On the 13th December salvinia plant had completely disappeared from the water surface. Dying of salvinia plant may be attributed to the release of substance from algae which may be harmful to the plant and also it may be that the new environment was not suitable for plants. But the actual cause of dying was not known.

The removal efficiency observed for the loading 41 kg COD/(ha.d) for different parameters is shown in the Table 4.6.

Table 4.6 Removal efficiency for 3 different aquatic systems for organic loading 41 kg/(ha.d).

Systems	Removal(%) for parameters				
	TS	SS	COD	TKN	TP
Hyacinth pond	12.1	84.7	77.7	70	73
Water lily pond	6.0	49.0	43.5	58	33
Salvinia pond	16.1	69.0	70.9	83	38

Salvinia pond system topped in removing TS and TKN from the wastewater. For the removal of SS, COD and TP, the hyacinth pond was the most efficient followed by the salvinia pond. Removal efficiency in the water lily pond was lowest as compared to water hyacinth and salvinia ponds.

Removal efficiency for the two pond systems with hyacinth and water lily is shown in Table 4.7.

Table 4.7 : Removal efficiency of the pond systems with water hyacinths water lilies for organic loading 86 kg COD/(ha.d).

Pond system	Removal (%) for parameters				
	TS	SS	COD	TKN	TP
Hyacinth pond system	-1.7	64.0	80.7	80.0	65
Water lily pond system	0.2	32.0	72.9	69.7	25.7

4.7 General Discussion

TS removal was not significant for the pond system with the plant, water hyacinth, salvinia and water lily. Hyacinth pond system was the best in removing SS from the wastewater. Superiority of the hyacinth pond system over the other two systems may be attributed to the complete shading provided by the plants. Such complete shading never existed in water lily pond and salvinia pond. Pond system with water lily had some algae remained on the leave surface of water lily. Some portion of algae was discharged with the effluent whereas in salvinia pond, mostly filamentus algae appeared and settled down with the decaying plant. Effluent was almost clear of algae. However, mean SS concentration in salvinia and water lily pond systems were 15 and 26 mg/L respectively. In hyacinth pond, effluent SS was 8 mg/L(Appenix B).

In laboratory scale study, the hyacinth pond system was noticed to be the most effective as compared to the other two systems with salvinia and water lily in removing COD and TP and SS, but salvinia appeared better than hyacinth in removing TS and TKN from the wastewater.

DO Level

DO level was lowest in the water hyacinth system and maximum DO occured in salvinia pond system.

(a) Removal of COD,TKN and TP (mass) from the systems for the organic loading 41 kg COD/(ha.d) and flowrate 130 L/d

Hyacinth pond:

COD removed = 32 kg/(ha.d)

TKN removed = 3.7 kg/(ha.d)

TP Removed = 3.6kg/(ha.d)

Water lily pond:

COD = 17.56 kg/(ha.d)

TKN = 3.12 kg/(ha.d)

TP removed = 0.2 kg/(ha.d).

Salvinia:

COD removed = 29.14 kg/(ha.d)

TKN removed = 4.48 kg/(ha.d)

TP removed = 0.23 kg/(ha.d).

(b) Removal of COD, TKN and TP from the system, for organic loading 86 kg COD/(ha.d) and flowrate 260 L/d

Hyacinth pond:

COD removed = 69.41 kg/(ha.d)

TKN removed = 8.12 kg/(ha.d)

TP removed = 0.72 kg/(ha.d).

Water lily pond:

COD removed = 62.77 kg/(ha.d)

TKN removed = 7.04 kg/(ha.d)

TP removed = 0.27 kg/(ha.d).

From the above results COD, TKN and TP (mass) removed from the systems were higher at higher organic loadings for the ponds with hyacinth and water lily.

V CONCLUSIOS AND RECOMMENDATIONS

5.1 Conclusions

1. Results obtained during the observation period in full-scale study showed that hyacinth ponds system was efficient in removing SS, COD, TKN and TP from the wastewater as compared to the free pond (without plant). Clear effluent from the hyacinth pond was obtained as compared to the greenish and algae laden effluent from the free pond.

2. Suspended solids are greatly reduced by the simple mechanism of shading in hyacinth pond system and the prevention of algal growth.

3. Removal of total solid is not significant in hyacinth system and almost nil in the oxidation pond. So it was infered that hyacinth pond system was not efficient in removing the dissolved solids which is the major constituent of total solids.

4. Algae production in the free pond contributes suspended solid and COD in the effluent whereas, in hyacinth pond no such case occured.

5. The percentage reduction for mean SS, COD, TKN and TP for the free pond system were -15.7,-2.9, 28.5 and -5.4% and for the hyacinth pond system the corresponding reductions were 74.9, 72.7, 70 and 68.2% respectively.

   Mean COD, TKN and TP load were removed at 83.3 kg/(ha.d) (78 %) 7.89 kg/(ha.d)(76 %) and 1.1kg/(ha.d) (74.8 %) in the hyacinth pond system, whereas in free pond system the corresponding loads (mean) removed were at 19.8 kg/(ha.d) (20 %) , 4.5 kg/(ha.d) (44.4 %) and .26 kg/(ha.d) (18.30 %) respectively. Similarly at 100 % hyacinth coverage, COD, TKN and TP loads were removed at 84.1 kg/(ha.d)(84 %), 6.2 kg/(ha.d) (79.6%) and 1.08 kg/(ha.d) (79.4 %) respectively. For free pond system, COD, TKN and TP were removed at 21.5 kg/(ha.d) (24 %), 3.4 kg/(ha.d) (44.8 %) and 0.26 kg/(ha.d) (22 %) respectively.

6. The results from the laboratory scale study showed that the hyacinth pond system's performance was the best in removing the SS, COD and TP as compared to water lily and salvinia pond systems. Salvinia pond appeared to be efficient in removing TS and TKN for organic loading of 41 kg COD/(ha.d) as compared to the hyacinth and water lily ponds.

5.2 Recommendation

1. Period of observation should be increased to minimum of 1 year so as to obtain reliable data for responses of the system before adopting aquatic plant system.

2. Harvesting of hyacinths should be investigated for their proper utilizations in removing organic and inorganic pollutants from the wastewater.

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APPENDIX - A

COMPARISON OF AIT WASTEWATER TREATMENT SYSTEM (OXIDATION POND)

WITH AND WITHOUT WATER HYACINTH

LABORATORY REPORT OF DIFFERENT PARAMETERS ANALYSED FOR INFLUENT AND

EFFLUENT CHANNEL OF FREE POND (WITHOUT PLANT) AND WATER HYACINTH POND

Sampling Date	Sampling Time	Analysis Date	Analysis Time	TSfi mg/L	TSfe mg/L	Removal %	TShi mg/L	TShe mg/L	Removal %	SSfi mg/L	SSfe mg/L	Removal %	SShi mg/L	SShe mg/L	Removal %	CODfi mg/L	CODfe mg/L	Removal %
27.10.86	6:40	27.10	18:30	634	612	3.47	650			49	105	-114.29	57	39	31.58	63.2	69.1	-9.34
30.10.86	8:45	30.10	20:45	595	595	0.00	891	660	25.93	39	72	-84.62	38	37	2.63	105.6	67.2	36.36
2.11.86	8:30	2.11	20:00	699	693	0.86	666	612	8.11	24	46	-91.67	30	40	-33.33	125	83.98	32.92
5.11.86	7:47	5.11	11:50	688	705	-2.47	699	593	15.16	20	61	-205.00	43	7	83.72	98.6	65.2	33.87
8.11.86	3:00	8.11	18:00	630	712	-13.02	660	556	15.76	54	134	-148.15	66	22	66.67	102.96	75	27.16
11.11.86	11:30	11.11	12:00	720	676	6.11	746	570	23.59	40	84	-110.00	56	30	46.43	74.4	89.9	-20.83
14.11.86	18:00	14.11	20:00	713	684	4.07	622	595	4.34	77	67	12.99	51	13	74.51	109.5	101.7	7.12
17.11.86	17:30	17.11	19:30	652	688	-5.52	805	579	28.07	65	63	3.08	49	14	71.43	98	113.68	-16.00
20.11.86	11:15	20.11	15:30	724	675	6.77	656	590	10.06	77	82	-6.49	61	25	59.02	116	120.28	-3.69
23.11.86	19:00	23.11	22:45	589	741	-7.55	713	637	10.66	41	53	-29.27	33	11	66.67	98	209	-113.27
26.11.86	9:30	26.11	11:00	670	752	-12.24	684	623	8.92	56	58	-3.57	54	24	55.56	117.1	101.5	13.32
29.11.86	10:30	29.11	12:00	1136	1308	-15.14	1216	632	48.03	84	80	4.76	88	9	89.77	133.33	113.1	15.17
4.12.86	18.00	4.12	20:00	790	812	-2.78	797	706	11.42	37	44	-18.92	50	9	82.00	129.4	74.5	42.43
8.12.86	15:30	8.12	18:00	930	785	15.59	592	737	-24.49	65	77	-18.46	90	10	88.89	98.5	143	-45.18
10.12.86	18:00	10.12	20:00	838	776	7.40	808	599	25.87	35	51	-45.71	31	12	61.29	87.4	161	-84.21
13.12.86	8:00	13.12	10:00	810	780	3.70	795	645	18.87	50	64	-28.00	45	11	75.56	85.1	97	-13.98
16:12:86	12:00	16.12	15:00	790	686	13.16	750	638	14.93	64	50	21.88	84	10	88.10	118.6	104.52	11.87
20:12:86	11:00	20:12	12:00	634	706	-11.36	678	554	18.29	40	40	0.00	36	6	83.33	104.9	95.04	9.40
22:12:86	9:30	22:12	11:30	708	840	-18.64	742	670	9.70	74	60	18.92	55	16	70.91	93	93.01	-0.01
26:12:86	18:00	26:12	19:30	668	706	-5.69	672	624	7.14	38	38	0.00	46	16	65.22	71	97.3	-22.96
28:12:86	11:00	28:12	12:30	582	626	-7.56	526	620	0.96	36	22	38.89	56	7	87.50	108	104	3.70
30:12:86	11:30	30:12	12:15	620	610	1.61	582	562	3.44	64	44	31.25	56	9	83.93	82.8	88.6	-7.00
1:1:87	12:00	1:1	13:30	601	595	1.00	530	504	4.91	54	56	-3.70	82	8	90.24	106	68	35.85
8:1:87	12:00	7:1	14:30	704	694	1.42	694	642	7.49	54	58	-7.41	48	6	87.50	85.98	88	-2.47
15:1:87	11:30	15:1	14:00	656	680	-3.66	828	638	22.95	44	30	31.82	40	5	87.50	83.7	89.6	-7.05
22:1:87	12:00	22:1	13:30	680	687	-1.03	761	640	15.90	40	52	-30.00	38	5	86.84	105.4	132.73	-25.93
29:1:87	12J00	29:1	12.00															
31:1:87	11.00	31:1	11.00															
Avg				713.9	724	-1.595	728.	617.0	13.439	50.80	61.1	-30.064	53.19	14.4	67.440	100.05	101.38	-3.9552
STD				115.7	132.5	8.2439	128.	48.90	12.641	16.34	22.9	59.2215	16.71	10.5	28.401	17.355	31.506	35.0362

Sampling Date	CODhi mg/L	CODhe mg/L	Removal %	TKNfi mg/L	TKNfe mg/L	Removal %	TKNhi mg/L	TKNhe mg/L	Removal %
27.10.86	65.1	30.96	52.44	5.59	7.61	-36.14	9.8	2.25	77.04
30.10.86	86	35.72	58.47						ERR
2.11.86	121.6	47.5	60.94	9.96	4.7	52.91	8.79	1.62	81.57
5.11.86	80.9	39.6	50.99	10.69	5.79	45.84	8.37	1.54	81.60
8.11.86	110.99	49	55.91	10.68	18.93	-199.53	16.02	5.7	64.42
11.11.86	78.2	35.2	54.99	15.06	11	-12.94	16.29	4.54	72.13
14.11.86	113.4	39.12	65.50	16.41	6.49	34.90	16.46	4.09	75.15
17.11.86	117.5	52.8	55.10	14.08	14.44	-61.16	13.44	6.38	52.53
20.11.86	151.32	42.69	71.79	14.33	14.28	-55.56	13.85	6.7	51.62
23.11.86	68.4	22.9	66.67	11.8	7.13	24.95	14.2	6.5	54.23
26.11.86	122.5	50.75	58.57	14.39	7.18	12.22	14.44	6.55	54.64
29.11.86	161.6	46.08	71.49	9.73	3.35	64.36	9.02	4.26	52.77
4.12.86	98	36.04	63.22	9.37	6.256	32.88	7.5	2.18	70.93
8.12.86	147	13.72	90.67	11.6	10.4	-65.08	9.7	1.9	80.41
10.12.86	100.7	14.7	85.40	6.9	5.2	23.53	5.7	1.17	79.47
13.12.86	101.2	15.2	84.98	13	7.3	43.85	12.9	1.8	86.05
16:12:86	104.52	14.29	86.34	10.42	6.5	37.62	9.7	1.96	80.82
20:12:86	97.02	21.2	78.15	9.24	4.39	52.60	9.87	1.9	80.75
22:12:86	99	16.65	83.18	5.58	3.99	28.67	6.75	2.34	65.33
26:12:86	83.1	18.95	77.28	6.6	5.16	21.82	6.4	2.25	64.84
28:12:86	104.22	18.6	82.15	8.62	8.72	-1.16	9.8	1.94	80.20
30:12:86	127.9	18.06	85.87	4.66	4.03	13.52	5.01	1.23	75.45
1:1:87	114	23	79.82	4.2	4.21	-0.24	4.04	1.3	67.82
8:1:87	87.81	19.75	77.52	9.7	4.75	51.03	8.7	1.45	83.33
15:1:87	87.7	21.5	75.48	9.3	8.83	5.05	11.85	1.54	87.00
22:1:87	97.6	19.52	80.00	9.52	5.52	42.62	10.58	2.3	78.26
29:1:87									
31:1:87									
Avg	104.9	29.3607	71.2623	10.247	7.4385	8.02565	10.39	3.043	71.7231
STD	23.577	12.9638	12.1478	3.1776	3.9061	55.5967	3.569	1.922	11.3563

Sampling Date	TPfi mg/L	TPfe mg/L	Removal %	TPhi mg/L	TPhe mg/L	Removal %	DOfi mg/L	DOfe mg/L	DOhi mg/L	DOhe mg/L
27.10.86										
30.10.86										
2.11.86	1.23	0.84	31.71	1.24	0.8	35.48	0.2	1.2	0.2	1.4
5.11.86	1.68	2.04	-21.43	1.92	0.46	76.04				
8.11.86	0.5	2.1	-320.00	0.85	0.15	82.35	0.2	3.6	0.7	1.3
11.11.86	1.05	1.1	-4.76	1.13	0.65	42.48	0.3	5.3	1.2	1.2
14.11.86	2.05	2.6	-26.83	1.74	0.88	49.43	0.2	6.2	2.5	1.5
17.11.86	1.75	1.8	-2.86	1.9	1.02	46.32	0.1	5.9	1.5	1.3
20.11.86	0.58	0.7	-20.69	0.68	0.22	67.65	0.2	3.7	0.6	1.2
23.11.86	1.62	1.35	16.67	1.95	0.47	75.90	0.8	2.2	1.1	1.1
26.11.86	1.52	1.47	3.29	1.03	0.5	51.46	0.2	2.4	0.4	2.1
29.11.86	2	1.6	20.00	2	0.48	76.00	0.1	2.4	0.2	1.4
4.12.86	2.7	2.1	22.22	1.92	0.5	73.96	1.1	2.7	0.9	1.3
8.12.86	1.54	3.5	-127.27	1.25	0.25	80.00	0.9	2.8	0.7	1.5
10.12.86	1.85	1.5	18.92	1.6	0.45	71.88	0.3	2.6	0.2	1.2
13.12.86	2.2	1.7	22.73	2.3	0.6	73.91	1.4	2.7	0.9	1.5
16:12:86	1.55	1.4	9.68	1.5	0.42	72.00	0.4	2.9	0.3	1.4
20:12:86	1.45	1.5	-3.45	1.5	0.65	56.67				
22:12:86	1.25	0.95	24.00	1.3	0.36	72.31				
26:12:86	1.24	1.03	16.94	1.05	0.34	67.62				
28:12:86	0.95	1.51	-58.95	1.35	0.6	55.56				
30:12:86	0.85	0.9	-5.88	1.15	0.3	73.91				
1:1:87	0.75	1.05	-40.00	1.35	0.22	83.70	0.3	4	0.5	0.6
8:1:87	0.95	1.2	-26.32	1.15	0.3	73.91	0.3	1.2	0.4	0.5
15:1:87	1.75	1.55	11.43	1.65	0.67	59.39	0.4	4.1	0.4	0.3
22:1:87	1.97	1.6	18.78	2.01	0.125	93.78	0.3	2.7	0.4	0.5
29:1:87							0.4	7.2	0.3	0.3
31:1:87							0.3	7.6	0.4	0.3
Avg	1.457	1.545	-18.419	1.48	0.475	67.154				
STD	0.532	0.604	71.4169	0.411	0.223	14.113				

APPENDIX - A-1

Flow Rate Measurement by Calibrated V-Notch Weir.

Date	FI*	HI#	Fe**	He##
9 - 1 - 87	--	--	--	4.23
10 - 1 - 87	--	--	--	4.02
11 - 1 - 87	--	--	--	4.26
12 - 1 - 87	--	--	--	3.86
13 - 1 - 87	--	--	--	----
14 - 1 - 87	--	--	--	4.05
15 - 1 - 87	--	--	--	4.45
16 - 1 - 87	--	--	--	4.45
17 - 1 - 87	--	--	--	----
18 - 1 - 87	--	--	--	----
19 - 1 - 87	--	--	--	----
20 - 1 - 87	5.41	5.59	--	4.45
21 - 1 - 87	6.15	5.63	--	----
22 - 1 - 87	--	--	--	----
23 - 1 - 87	6.04	5.09	--	4.55
24 - 1 - 87	5.88	4.78	--	4.40
28 - 1 - 87	--	--	--	4.47
30 - 1 - 87	--	--	--	4.08
31 - 1 - 87	--	--	--	4.34
1 - 2 - 87	--	--	--	4.25
2 - 2 - 87	--	--	--	4.05
7 - 2 - 87	5.04	5.56	4.65	----
8 - 2 - 87	5.29	5.78	3.78	----
9 - 2 - 87	5.56	5.42	4.58	----
10 - 2 - 87	5.46	5.13	4.51	----
11 - 2 - 87	5.26	5.16	3.92	----
12 - 2 - 87	5.41	4.54	3.92	----
13 - 2 - 87	5.53	5.34	4.82	----
14 - 2 - 87	5.38	5.25	4.02	----
15 - 2 - 87	5.43	5.45	4.35	----
16 - 2 - 87	5.55	5.67	4.47	----
17 - 2 - 87	5.72	5.56	4.45	----
18- 2 -87	5.60	5.50	4.20	-----
19 - 2 - 87	5.63	5.55	4.35	-----
Avg:	5.55	5.35	4.31	4.26

*

FI = Free Pond, Influent in L/s

HI** = Hyacinth Pond Influent in L/s.

Fe# = Free Pond Effluent in L/s

He## = Hyacinth Pond Effluent L/s

APPENDIX - B

LABSCALE EXPERIMENT 1

Influent Flowrate : 0.1296 m^3/d

Loading Rate : 41.7kg COD/(ha.d)

Detention time : 24 days

Area Of Pond : 3.85 ng^2

Volume of Pond : 1.94 m^3

Hydraulic Loading : 334 m^3/d

Date	Analysis time	TSrv mg/l	SSrv mg/l	CODr mg/	TKNrv mg/L	TPrv mg/L	DOrv mg/L	TSvbe mg/L	Removal %	SSvb mg/l	Removal %	CODvbe mg/l	Removal %	TKNvbe mg/L	Removal %	TPvbe mg/l	Removal %	DOvbe mg/L
2:11	20.00			135.0														
5:11	11.30			216.0								70.53	57.23					
8:11	16.00	776	23	162.4	9.55	0.75		608	21.55	14		43.20	73.40	6.20	35.08	0.45	40.00	
11:11	13.25	740	146	156.0	19.26	2.30	0.1	624	15.68	14	90.41	50.25	67.40	6.72	65.11	0.60	78.57	0.2
18:11	21.15	681	42	153.6	18.70	3.27	0.2	698	-2.50	10	76.19	59.12	55.00	7.97	57.33	0.82	74.92	1.2
22:11	13.00	569	40	195.2	13.40	1.70	0.3	556	2.28	3	30.00	30.60	64.33	7.10	61.41	0.65	61.76	1.1
25:11	17.00	530	35	150.2	16.10	2.50	0.2	575	0.66	7	30.00	20.20	33.55	6.37	50.43	0.70	72.00	1.3
29:11	12.00	715	30	110.0	13.20	2.90	0.2	510	14.30	10	55.67	17.12	34.44	6.34	65.15	0.50	82.76	1.2
4:12	14.30	574	44	112.0	15.07	1.40	0.3	497	-3.41	7	84.09	19.01	53.03	4.30	71.47	0.30	78.57	1.4
8:12	14.00	930	35	89.0	15.01	0.37	0.3	592	36.34	5	35.71	15.50	31.46	2.50	85.34	0.24	72.41	1.3
10:12	13.00	306	52	144.0	12.91	0.30	0.2	732	9.18	6	33.46	12.30	67.29	3.25	74.83	0.25	66.73	1.2
13:12	17:00	537	45	113.0	14.30	0.95	0.3	695	16.97	5	38.39	15.30	57.33	1.75	66.18	0.40	57.39	0.9

Date	Analysis time	TSvie mg/L	Removal %	SSvie mg/L	Removal %	CODvie mg/L	Removal %	TKNvie mg/L	Removal %	TPvie mg/L	Removal %	DO mg/L
2:11	20.00											
5:11	11.30					86.30						
8:11	16.00	578	12.53	58		60.38	62.53	9.41	1.47	1.00	-33	
11:11	13.25	666	7.30	50	58.90	54.76	64.90	9.24	52.02	1.70	39	0.2
18:11	21.15	746	-5.14	13	69.05	71.68	53.33	7.38	59.47	2.01	39	0.2
22:11	13.00	633	-12.13	63	-57.50	208.00	-6.55	8.20	55.43	2.15	-25	0.3
25:11	17.00	656	-13.19	29	42.36	150.00	0.13	7.40	54.04	2.00	20	0.2
29:11	12.00	572	20.11	13	56.57	22.29	70.73	7.26	60.11	0.05	95	1.0
4:12	14.30	708	-5.04	19	56.32	29.00	74.11	5.21	64.76	1.15	18	2.1
8:12	14.00	785	15.59	18	46.57	37.50	57.37	6.53	56.16	1.00	-15	2.0
10:12	13.00	722	10.42	17	57.31	38.30	74.45	4.94	61.74	0.60	25	1.6
13:12	17:00	710	15.17	16	64.44	38.70	67.20	5.30	64.19	0.70		

Date	Analysis time	TSsie mg/L	Removal %	SSsie mg/L	Removal %	CODsie mg/L	Removal %	TKNsie mg/L	Removal	TPsie mg/l	Removal %	DO mg/
2:11	20.00											
5:11	11.30					56.60						
8:11	16.00	584	24.74	34	-21.43	37.90	76.56	3.18	66.70	0.40	46.7	
11:11	13.25	586	20.31	40	72.60	46.94	69.91	4.03	79.08	1.30	53.6	0.5
18:11	21.15	692	-1.62	13	69.05	65.23	57.50	2.10	86.77	0.75	77.1	0.6
22:11	13.00	680	-19.51	15	62.50	30.10	34.58	2.25	37.77	0.30	52.9	0.5
25:11	17.00	675	-16.38	14	60.00	29.03	80.37	2.90	81.99	1.20	52.0	1.5
29:11	12.00	564	21.23	10	66.67	33.50	69.45	2.90	84.07	2.20	20.7	1.6
4:12	14.30	646	4.15	12	72.73	30.20	73.04	2.64	82.48	2.70	-92.9	2.4
8:12	14.00	737	20.75	11	68.57	31.60	64.49	2.70	82.01	0.60	31.3	2.1
10:12	13.00	722	10.42	15	71.15	28.90	79.93	2.55	80.25	0.40	50.0	1.3
13:12	17:00											

APPENDIX - C

LABSCALE EXPERIMENT 2

Influent Flowrate : 0.2592 m^3/(ha.d)

Loading Rate : 85.86 kg COD/(ha.d)

Detention Time : 12 days

Area of Pond : 3.88 m^2

Hydraulic Loading : 668 m^3/(ha.d)

Sampling Date	Time	Analysis Date	Time	TSrv mg/L	Tsvhe mg/L	TSvl mg/L	SSrv mg/L	SSvhe mg/L	SSvle mg/L	CODrv mg/L	CODvhe mg/L	CODvle mg/L	TKNrv mg/L	TKNvhe mg/L	TKNvle mg/L	TPrv mg/L	TPvhe mg/L	TPvle mg/L	DOrv mg/L	DOvhe mg/L	DOvle mg/L
9:1:87	12:00	9:1	13:30	718	746	584	38	6	12	109.80	24.30	26.70	14.17	1.66	3.23	2.10	0.30	0.50	1.70	0.50	2.60
12:1:87	12:00	12:1	13:30	724	742	742	20	5	10	123.01	16.33	26.90	14.43	2.60	3.46	1.95	0.42	0.87	0.50	0.60	2.50
15:1:87	11:30	15:1	14:00	540	795	719	28	6	19	149.10	25.30	27.70	17.66	3.12	5.10	2.00	0.50	1.62	0.60	0.50	2.00
18:1:87	12:15	18:1	15:00	712	706	772	30	10	20	148.50	28.80	50.48	14.22	2.82	4.08	1.15	0.57	0.78	0.40	0.20	2.30
20:1:87	17:15	20:1	18:00	868	780	790	22	14	18	145.50	27.60	37.60	16.53	2.69	4.87	1.25	0.45	1.75	0.40	0.20	2.80
21:1:87	19:00	21:1	21:00	794	790	752	18	12	21	113.20	24.40	34.50	15.61	3.47	5.02	1.45	0.92	1.75	0.40	0.20	2.60
22:1:87	16:00	22:1	18:00	800	750	760	22	11	20	121.02	25.98	37.86	13.14	3.48	5.44	1.90	0.80	1.40	0.20	0.00	2.50
23:1:87	25:30	23:1	17:30	700	650	725	27	10	19	119.20	25.30	36.90	14.20	3.05	5.17	1.50	0.75	1.35	0.20	0.10	2.40