USE OF WATER HYACINTH FOR REMOVAL OF POLLUTANTS IN SEWAGE

A Thesis

By

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Submitted to the Department of civil Engineering, Bangladesh University of Engineering & Technology, Dhaka. in partial fulfillment of the requirements for the degree

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DECLARATION

I here by declare that the research work reported in this thesis work was performed by me as a partial fulfillment of the requirements for the degree of Masters of Science in Civil Engineering from Bangladesh University of Engineering & Technology,(BUET)Dhaka.

This thesis contains no material which has been accepted for the award of any other degree or diploma from any other institution and to the best of my knowledge and belief, this thesis contains no material previously published or written by any other person, except when due reference is made in the text of this thesis.

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ABSTRACT

The study is an experimental investigation into the use of water hyacinth for removal of pollutants in sewage. This system is considered as low cost technology, alternate to conventional treatment system for sewage treatment in hot climates. Cost estimates for sewage treatment in ponds system using water hyacinth and without water hyacinth is compared. Ponds with water hyacinth has been found cheaper than conventional treatment system.

From the literature review it was apparent that little work had been carried out on pollutant removal process from sewage using water hyacinth. The shallower depths and the presence of water hyacinths in place of algae are the major differences between treatment systems with water hyacinths and stabilization ponds. The water hyacinths, themselves, bring about little actual treatment of the waste water. Their function is to provide components of the aquatic environment that improve the waste water treatment capability and/or reliability of that environment.

Survival and growth rate of water hyacinth were observed, when this plant was grown on sewage. Longer type water hyacinth is seen continue to survive in sewage having maximum initial BOD_5 of 110 mg/l.

Evapotranspiration and Evaporation rate from sewage with and without water hyacinths were determined in various conditions. Three types of water hyacinths were used to determine evapotranspiration rate from different concentration of sewage sample. Evaporation rate from sewage sample were determined in similar condition to evapotranspiration test. Evapotranspiration rate is seen 2 to 4.5 times higher than evaporation rate in the similar condition.

Characterization of pollutant removal from sewage with water hyacinth were done in various conditions primary importance was given to findout the removal performance of organic loadings, suspended solids (ss) and Nutrient Concentration (P&N).

Higher pollutants removal rate have been found in case of sewage treatment with water hyacinth than without water hyacinth. In general removal of organic matter in water hyacinth system is 8-15% and removal of other pollutants are 10-25% greater than without water hyacinth system.

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LIST OF ABBREVIATIONS

ATU:	Aquatic treatment unit
BOD:	Bio chemical oxygen demand
COD:	Chemical oxygen demand
DO:	Dissolved oxygen
FC:	Faecal coliform
LPC:	Leaf protein concentration
NOD:	Nitrogeneous oxygen demand
NTU:	Nephelometric turbidity units
ThoD:	Theoretical oxygen demand
TC:	Total Nitrogen
TSS:	Total suspeneded solids

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Disposal of sewage into rivers/lakes without removing pollutants were common in many developing countries. The treatment and disposal of sewage did not receive much attention because the extent of the nuisance caused by the discharge of untreated sewage into the relatively large bodies of water was not severe, and because large areas of land suitable for disposal were available. But by the early 1900s, however, nuisance and health conditions. brought about an increasing demand for sewage treatment. It is clearly understood that if untreated sewage is allowed to accumulate, the decomposition of the organic materials it contains can lead to the production of large quantities of malodorous gases. In addition it usually contains numerous pathogenic or disease-causing micro-organisms. It also contains nutrients and toxic compounds.

Different methods for removing pollutants from sewage have been developed such as physical unit operation, chemical or biological unit process. Among these, biological method is one of the effective and low cost system for pollutant removal. According to a survey made in 1974 in USA, stabilization ponds are the most commonly used means of treatment in facilities with flow rates of 439 cm^3/Sec or less(Metcalf and Eddy,1985).

At present, most of the unit operations and process used for sewage treatment are undergoing continual and intensive investigation from the stand point of implementation and application. As a result, many modifications and new operations and processes have been developed and implemented: more need to be made to meet the increasingly stringent requirements for environmental enhancement of water courses. In addition to the developments taking place with conventional water courses. In addition to the developments taking place with conventional treatment methods, alternative treatment systems and technologies are also under-study. Aquatic treatment system using water hyacinth is one of them. In addition to treatment, aquatic systems can be used for the capture of solar energy and for the utilization of the nutrients in sewage. The potential for producing usable plant and animal protein is another possible advantage of such systems.

The organic load of river systems in Bangladesh is a major problem, specially in dry season. Pollution control due to sewage discharges into lakes/rivers is considered to be uneconomical in most of the developing countries. However, considering the social responsibility and other indirect advantages of pollution control, it is essential to have pollution control for sewage. In this study a treatment process for removal of pollutants from sewage with water hyacinth has been studied. The study includes removal of organic matter, nutrients, Suspended solids and other pollutants from sewage with and without waterhyacinth. Also similar study is conducted without waterhyacinth. Removal performance found from this study is analyzec and attempts have been made to find out a suitable environment for removal of pollutants in sewage with water hyacinth

1.2. FEASIBILITY STUDY WITH RESPECT TO BANGLADESH

Water hyacinth *(Eichhornia Crassipes)* is a beautiful vascular aquatic plant. Its rapid growth and proliferation indicate fullest exploitation of aquatic nutrients especially from polluted waters and highly efficient utilization of solar energy for profuse production and wonderful adaptation to local environment.

Bangladesh is a tropical region having hot climates and short duration of winter. Bangladesh is a low lying area. Water hyacinth is found common in all the areas of Bangladesh. Climatic condition and topography of such region is very favourable for growth and survival of water hyacinth. Biological treatment of sewage is best suitable. Thus water hyacinth can be used to remove pollutants from sewage in stabilization pond as an alternative methods of treating sewage. Because in this country, the climatic conditions are well suited to low cost methods of treatment. The value of such process is that they offer a real alternative to process that do not require imported or any other major pieces of equipment, permit the use of local labour, take advantage of warmth sunlight to provide free energy for supplying oxygen.

Thus Water hyacinth can be suitably used for sewage treatment in a mass populated area, which is far away from town. For example cantonment established out side of the city, large industrial complex, educational institution etc. Due to many demands in these organization and with generally poor finances, sewage treatment has not received the priority it should have.

Water hyacinth as a natural resources offers the prospect of socioeconomic benefits through scientific management and appropriate technological utilization. For a developing country like Bangladesh Water hyacinth can be utilized in agricultural uses. Production of paper and boards with Water hyacinth is another future prospect in industrial sector.

1.3 OBJECTIVES OF THE RESEARCH

Sewage treatment in developing countries have not yet received priority it desires. Discharge of untreated sewage into a water body is not still uncommon in many countries. Most often these countries can not make afford for the treatment of sewages due to poor finances availability of fund. Resources of the country may not make it possible to provide conventional treatment system(like trickling filter, aerated lagoon, high rate oxi- dation pond etc)of the medium and larger communities for many years to come. In some cases the treatment system have to be more oriented towards low cost technologies and utilization of sun light, temperature, labours and land facilities.

Sewage treatment in ponds with water hyacinth is to be one of the best method for this. Extensive research work is required to find out a suitable method for use of water hyacinth in sewage treatment. Keeping in mind the above stated situation and requirements, the objectives of this research work are selected as follows.

01. To asses the removal of pollutants from sewage with and without water hyacinth in different conditions.

02. To prepare a comparative study between pollutant removal rate with water hyacinth and without water hyacinth.

03. To develop a design criteria suitable for sewage treatment with water hyacinth in order to reduce the pollutant load in a considerable limit.

04. To summarize available information in the field of sewage treatment with Water hyacinth.

05. To observe the biological characteristics and response of water hyacinth when this plant is grown on sewage.

00. Determination of evaporation and evapotranspiration rate from sewage without and with Water hyacinth.

07. To identify areas which requires additional research.

1.4 ORGANISATION OF THE THESIS:

The study is presented in 7 chapters, the first of which is general introduction. Chapter 2 & 3 contains a brief and selective review of the relevant literature. In literature review conventional sewage treatment is discussed in chapter 2. Orientation with the water hyacinth pond system (also called aquatic treatment system) is done in chapter 3. Design facilities for the water hyacinth pond system is described in this chapter.

In chapter 4, experiments (based on evaporation and evapotranspiration) are described for determining the evapotranspiration rate from sewage with water hyacinth in different conditions. Evapotranspiration rate with water hyacinth is compared in this chapter. Growth rate and survival condition of water hyacinth is focussed on chapter 5, from which best suitable type of water hyacinth is selected for removal of pollutants in sewage.

Chapter 5 contains experimental investigation of organic matter removal rate from sewage in batch culture. Removal of organic matter from sewage in flowing condition is described in this chapter also. Removal characteristics of nutrients (N & P) from sewage and SS in water hyacinth pond system is included in this chapter.

In chapter 6, attempts are made to summarize various studies and to bring preliminary design guide lines. Conclusions and recommendations for further study are given in chapter 7. Recommendations presented in this chapter provides a basis for the future study.

CHAPTER 2

CONVENTIONAL TREATMENT SYSTEM FOR REMOVAL OF POLLUTANTS IN SEWAGE

2.1 INTRODUCTION

Methods of treatment in which the application of physical forces predominate are known as unit operations. Methods of treatment in which the removal of contaminants is brought about by chemical or biological reactions are known as unit processes. At the present time, unit operations and processes are grouped together to provide what is known as primary, secondary, and tertiary (or advanced) treatment. In primary treatment, physical operations, such as screening and sedimentation, are used to remove the floating and settleable solids found in sewage. In secondary treatment, biological and chemical processes are used to remove most of the organic matter. In tertiary treatment, additional combinations of unit operations and processes are used to remove other constituents, such as nitrogen and phosphorus, which are not removed by secondary treatment (Metcalf and Eddy 1985).

2.2 COMPOSITION OF SEWAGE

Sewage is the waste water of a community. It is a dilute mixture of the various kinds of wastes from residences, institutions, factories, business buildings, and manufacturing or industrial processes. It may be purely domestic in origin or it may contain some industrial or agricultural waste water as well. Domestic sewage is composed of human body wastes (faeces and urine) and sullage which is the waste water resulting from personal washing, laundry, food preparation and the cleaning of kitchen utensils.

Fresh sewage is a grey turbid which has an earthy but inoffensive odor. It contains large floating or suspended solids (such as faeces, rags, plastic containers, maize cobs), smaller suspended solids (such as partially disintegrated faeces, paper, vegetable peel) and very small solids in colloidal (i.e. non-settleable) suspension, as well as pollutants in true solution. It is objectionable in appearance and extremely hazardous in content, mainly because of the number of disease-causing ('pathogenic') organisms it contains. In hot climates sewage can soon lose its content of dissolved oxygen and so become 'stale' or 'septic'. Septic sewage has a most offensive odor, usually of hydrogen sulphide. Approximate analyses of human faeces and urine are given in Table 1.1

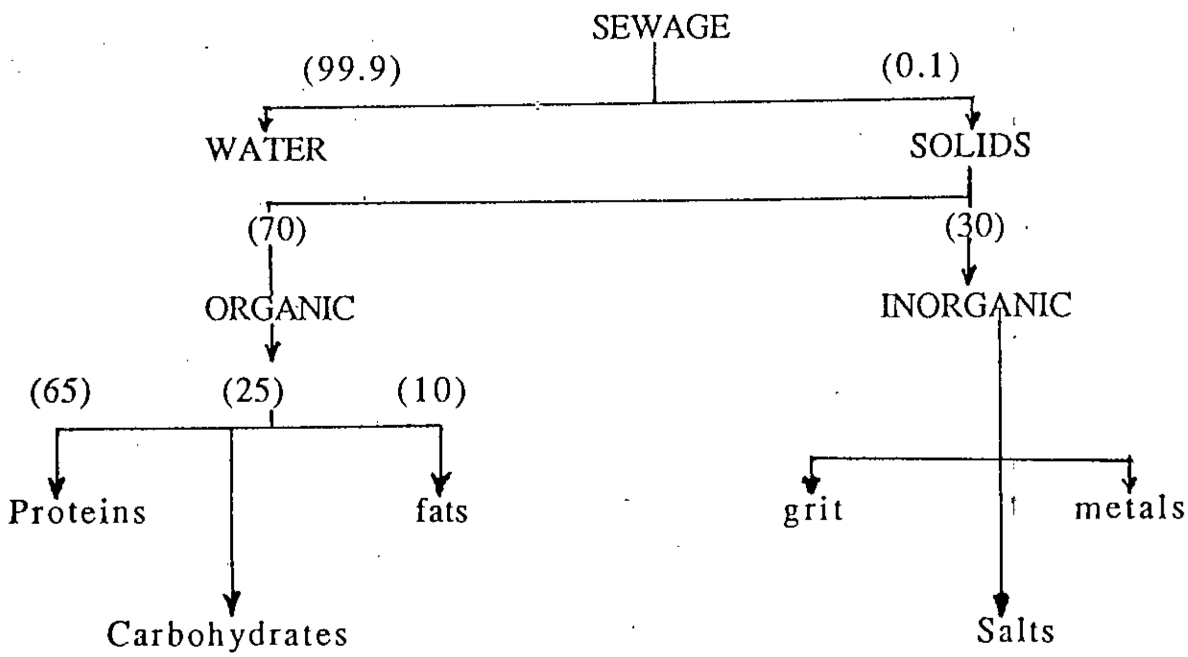

Fig. 2.1 Approximate Composition of sewage(Source: Tebbutt, 1970).

* Figure in ( ) indicate values in percentage.

Table 2.1 Composition of human faeces and urine(Gotaas ,1956)

	Faeces	Urine
Quantity(wet)per person per day	135_270 g	1.0_1.31 g
Quantity(dry solids) per person per day.	35_70 g	50_70 g
Approximate composition(%)		
Moisture	66_80	93_96
Organic matter	88_97	65_85
Nitrogen	5.0_7.0	15_19
Phosphorous (as P_2O_5)	3.0_5.4	2.5_5.0
Potassium (as K_2O)	1.0_2.5	3.0_4.5
Carbon	44_55	11_47
Calcium (as CaO)	4.5	4.5_6.0

The organic fraction of both is composed principally of proteins, carbohydrates and fats. These compounds, particularly the first two, form an excellent diet for bacteria, the microscopic organisms whose voracious appetite for food is exploited by sanitary engineers in the biological treatment of sewage. In addition to these chemical compounds, faeces and, to a lesser extent, urine contain many millions of intestinal bacteria and small numbers of other organisms.. The majority of these are harmless- indeed some are beneficial-but an important minority is able to cause human disease.

Sullage contributes a wide variety of chemicals-detergents, soaps, fats, and greases of various kinds, pesticides, anything in fact that goes down the kitchen sink and this includes such diverse items as sour milk, vegetable peelings, tea leaves, soil (arising from the preparation of vegetables) and sand (used to clean cooking utensils).

2.3 POLLUTANTS IN SEWAGE

Sewage collected in Municipal sewerage systems, having been put to a wide variety of uses, contains a wide variety of pollutants. A list of pollutants commonly found in municipal sewage along with their reason for importance is given in Table 2.2.

Quantitatively, constituents of sewage may vary significantly, depending upon the percentage and type of waste present and the amount of dilution from infiltration/inflow into the collection system. The composition of sewage from a given collection system may change slightly on a seasonal basis, reflecting different water uses.

The most significant components of sewage are usually suspended solids, biodegradable organic, and pathogens. Suspended solids are primarily organic in nature and are composed of some of the more objectionable material in sewage. Body wastes, food waste, paper, rags, and biological cells from the bulk of suspended solids in sewage.

2.4 POLLUTION AND COST CONSIDERATION IN POLLUTANT REMOVAL

To question the justifiability of removing a polluting material from waste water may seem invidious, regardless of cost. In considering this, the environmental engineer must decide what is meant by 'pollution". A working definition of pollution is that "it is a condition in which a medium or environment is rendered unfit for its desired purpose". The first implication of this is that pollution is not an absolute condition, but depends on the medium and its desired purpose.

For engineering process in general, the key consideration is one of cost. Treated waste-water has to achieve specified quality standards before it can be re-used, and standards strictly defined by law before it can be discharged to a waterway.

Table 2.2 Important Pollutants in Sewage (Metcalf and Eddy, 1985)

Pollutants	Reasons for Importance
Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions. When untreated wastewater is discharged into the aquatic environment.
Biodegradable organics	Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most commonly in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). If discharged untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions.
Nutrients	Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater.
Refractory organics	These organics tend to resist conventional methods of wastewater treatment. Typical example includes surfactant, phenols, and agricultural
Heavy metals	Heavy metals are usually added to waste water from commercial and industrial activities and may have to be removed if the wastewater is to be reused. It may be toxic to human body

The environmental engineer has the responsibility of meeting these requirements at minimal cost. This is of course the same for a production process, but while a production process can be evaluated in terms of profitability, the standards that a pollution control process has to meet may derive from criteria which are unquantifiable. Virtually any contaminant can be removed from water if enough suitable treatment processes are used. Two considerations then arise: first, whether the cost of removal is justified by the benefits resulting, and, secondly, what to do with a contaminant after it has been removed.

2.5 CONVENTIONAL ENGINEERED SYSTEM

Conventional treatment is the term used to describe the standard method of sewage treatment in temperate climates. It comprises four stages of treatment as follows:

(1) Preliminary treatment.
(2) Primary or physical treatment
(3) Secondary treatment
(4) Sludge treatment.

2.5.1 Preliminary Treatment

The first stage of sewage treatment is usually the removal of large floating objects. This is done in order to protect from damage the equipment used in the subsequent stages of treatment.

2.5.2 Primary Sedimentation

Primary sedimentation is a unit operation designed to concentrate and remove suspended organic solids from the sewage. In the primary sedimentation of sewage there are two aims: to produce high degrees of both clarification and thickening. Clarification is the removal of solids from the liquid phase and thickening the removal of liquid from the solid or sludge phase: A high degree of clarification is required to reduce the load on the secondary (biological) treatment plant and a high degree of thickening is desirable so that sludge handling and treatment (which usually accounts for 30 percent of the total cost of conventional treatment) is minimized.

Primary sedimentation is accomplished in either long-rectangular tanks or circular tanks. Scum removal in rectangular tanks is accomplished by having the sludge scrapers penetrate through the surface as they return to the effluent end of the tank.

Floating material is carried to a collection point some distance behind the effluent weirs where it is removed over a scum weir or by a transverse scum scraper. Circular tanks have a skimmer arm attached to the sludge-scraper drive mechanisms. The scum is wiped up an inclined apron and into a scum trough for removal. Separated scum is usually disposed of with screenings, unwashed grit, or digested sludge.

In large plants, the use of several rectangular tanks with common falls reduces construction costs and space requirements. Smaller plants tend to use circular tanks because of the simplicity of sludge removal. Some settling basin arrangements commonly used in primary treatment are shown in Figure 2.2. Sludge should be removed from the primary sedimentation tank before anaerobic conditions develop. If the sludge begins to decompose anaerobically, gas bubbles will be produced and will adhere to solid particles and lift them toward the surface.

The quantity of sludge removed in primary sedimentation may depend on several variables, including the strength at the incoming waste, the efficiency of the clarifier, and the conditions of the sludge (i.e, specific gravity, water content, etc.). Removal efficiencies of well-designed primary tanks depend upon overflow rates.

BOD removal relates only to the BOD of the solids removed, since no dissolved organics are removed and bio oxidation in the primary settling tank is negligible.

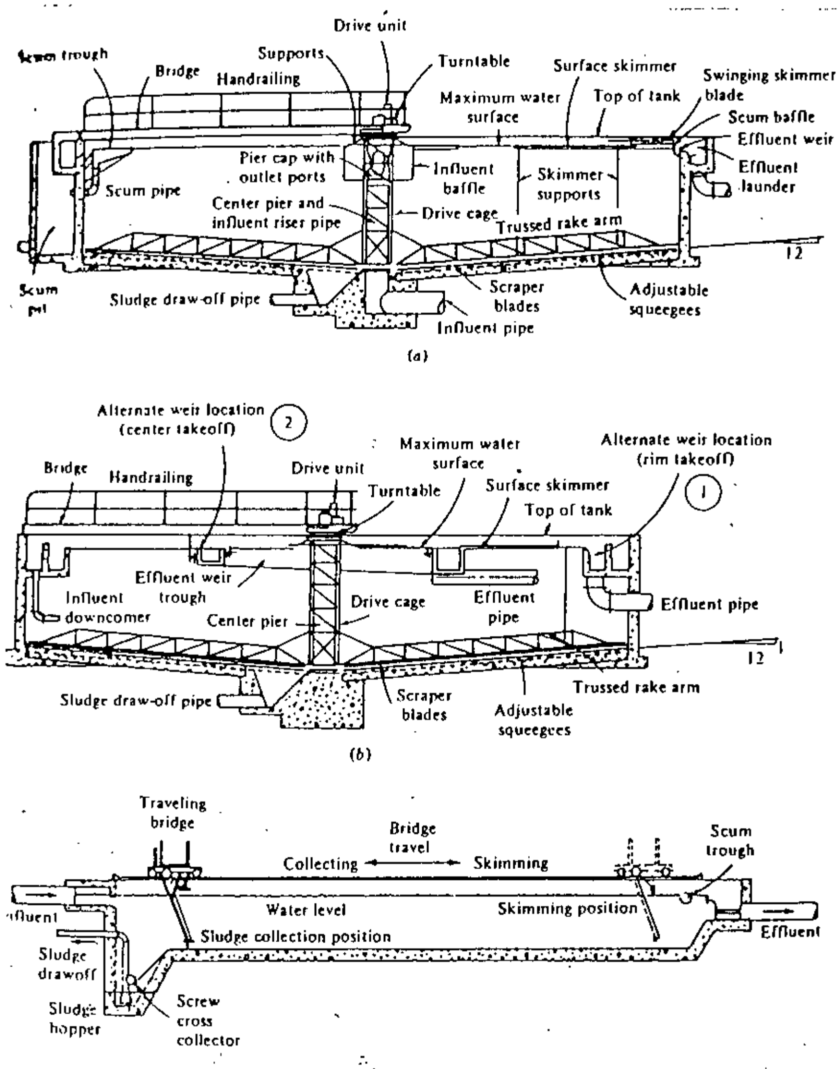

Fig. 2.2 Typical clarifiers: (a) circular basin, center feed. (b) circular basin rim feed (c) long rectangular basin.(Source: Peavy S. Howard, 1985).

2.5.3 Secondary or Biological Treatment

The effluent from primary treatment still contains 40 to 50 percent of the original suspended solids and virtually all of the original dissolved organics and in organics. This organic removal, referred to as secondary treatment, may consists of chemical-physical processes or biological processes. Currently, chemical-physical operations present a high-cost option with respect to both capital and operating expenses, and thus are not commonly used. Biological processes are used in practically all sewage treatment plant where secondary treatment is employed.

The biological treatment of waste waters is based on the apparently simple process in which a mixed population of micro-organisms utilize as nutrient substances contaminating the water. This is the mechanism by which healthy natural waterways, such as lakes and rivers, purify themselves. By using techniques of chemical engineering, this basic process has been intensified and accelerated to give the range of biological treatment systems currently in use for the large-scale purification of industrial and domestic waste-waters. Waste-waters containing polluting solutes are brought into contact with a dense population of suitable micro-organisms for a time sufficient for the microbes to break down and remove polluting solutes to the desired extent. In the natural process, solutes are removed principally by breakdown,usually oxidation, by microbial metabolism and conversion into microbial cell material. The intensified large scale process has an additional removal mechanism whereby pollutants are adsorbed and agglomerated on to the dense microbial masses used.

Considering a mass balance of BOD across a continuous operated biological reactor: the quantity of organic matter entering the reactor per day must equal the quantity leaving the reactor per day plus that removed by bio-oxidation. Now if Q is the flow in m^3/d and L_i and L_e are the influent and effluent BOD respectively in mg/L(=g/m^3), then: the equation for BOD removal is :

$$L_e = L_i e^{-k_1 t} \qquad (2.1)$$

This enables materials to be removed which would be unaffected by the other two mechanisms. The principal biological-treatment processes are:

(1) The activated-sludge process

(2) The trickling filters

(3) waste stabilization ponds

(4) Aerated lagoons. These are described in the following sections.

2.5.3.a Activated Sludge Process

The process is so named because it involves the production of an activated mass of micro-organisms capable of aerobically stabilizing a waste treatment with the activated sludge process is typically accomplished using a flow sheet such as that shown in Figure.2.3.

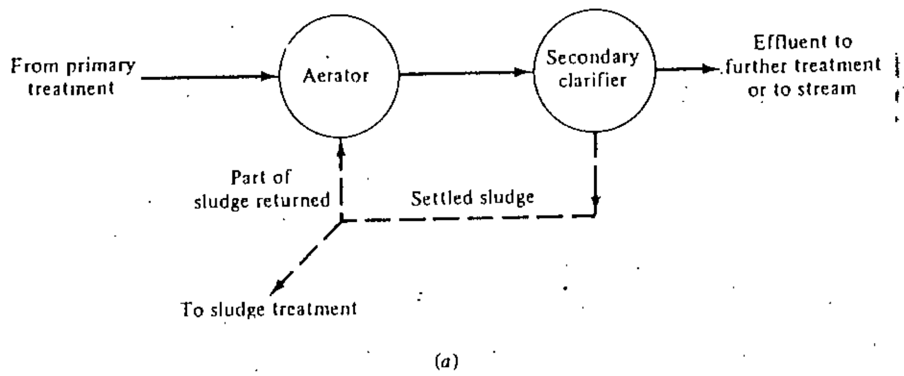

Fig. 2.3 Activated sludge process(Source: Howard P, 1985).

Organic waste is introduced into a reactor where an aerobic bacterial culture is maintained in suspension. The reactor contents are referred to as the mixed liquor. In the reactor, the bacterial culture carries out the conversion. The aerobic environment in the reactor is achieved by the use of diffused or mechanical aeration, which also serves to maintain the mixed liquor in a complete mixed regime. After a specified period of time, the mixture of new cells and old cells is passed into a settling tank where the cells are separated from the treated wastewater. A portion of the settled cells is recycled to maintain the desired concentration of organisms in the reactor, and a portion is wasted. The level at which the biological mass in the reactor should be kept depends on the desired treatment efficiency and other considerations related to growth kinetics.

2.5.3.b Trickling Filter

The liquid effluent from primary sedimentation tanks, termed 'settled sewage', is treated in one of two biological reactors, a trickling filter or an activated sludge process. The modern trickling filter consists of a bed of highly permeable media to which micro organisms are attached and through which sewage is percolated or trickled-hence the name. The filter media usually consists of rocks, varying in size from 25 to 100 mm (1 to 4 in) in diameter .The depth of the rock varies with each particular design but usually ranges from 0.9 to 2.5 m (3 to 8 ft) and averages 1.8 m (6 ft). Filters are constructed with an underlain system for collecting the treated waste water and any biological solids that have become detached from the media.

Settled sewage is distributed over the bed and trickles down over the surface of the aggregate. On these surfaces a microbial film develops and the bacteria, which constitute most of this film, oxidize the sewage as it flows past. As the sewage is oxidized the microbial film grows:

$$\text{Settled sewage + oxygen} \xrightarrow{\text{bacteria}} \text{oxidized effluent + new bacterial cells.}$$

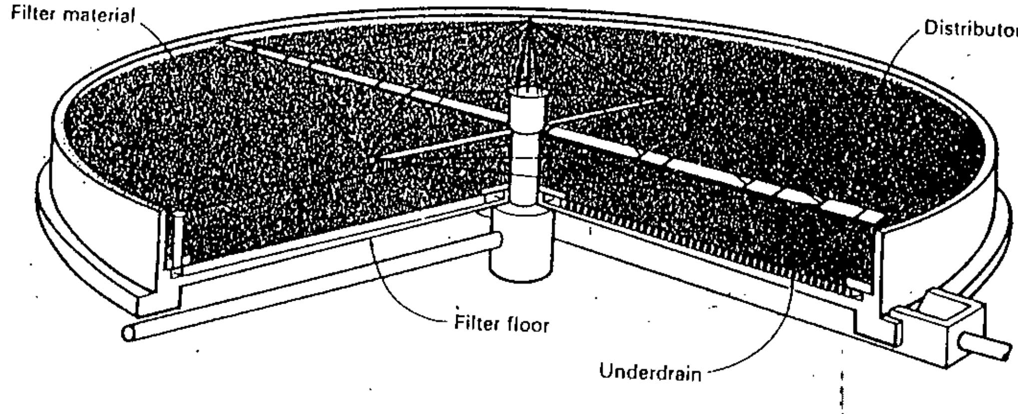

Fig 2.4 Trickling filter(Source: Howard P, 1985).

Some of the new cells so formed are washed away from the film by the hydraulic action of the sewage. These cells exert a high BOD and must be removed before the effluent is finally discharged. This is achieved in secondary sedimentation tanks. The clarified effluent is discharged usually to a river and the sludge pumped to the sludge treatment unit.

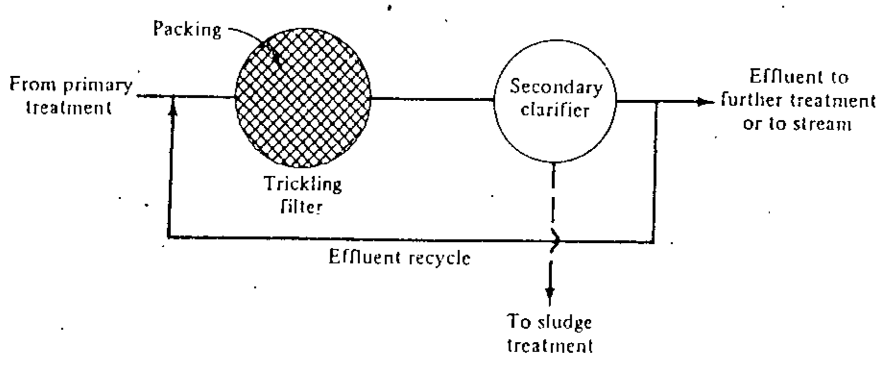

Fig. 2.5 Flow sheet showing trickling filter system(Source: Howard P, 1985).

2.5.3.c Waste Stabilization Ponds

Waste stabilization ponds are large shallow basins enclosed by earthen embankments in which raw sewage is treated by entirely natural process involving both algae and bacteria. The rate of oxidation is slow and as a result long hydraulic retention times are employed. They are without doubt the most important method of sewage treatment in hot climate where sufficient land is normally available and where the temperature is most favorable for their operation. There are three major types of ponds: facultative, maturation and anaerobic ponds. A fourth type is the high-rate pond which is still largely experimental. These are discussed below:

(a) Facultative Ponds:

These are the most common. They normally receive raw sewage or that which has received only preliminary treatment : they are, how ever, becoming increasingly used to treat the settled effluent from septic tanks and anaerobic pre treatment ponds. The term 'facultative' refers to a mixture of aerobic and anaerobic conditions and in a facultative pond aerobic conditions are maintained in the upper layers while anaerobic conditions exist towards the bottom.

Although some of the oxygen required to keep the upper layers aerobic comes from reaeration through the surface, most of it is supplied by the photosynthesis activity of the algae which grow naturally in the pond where considerable quantities of both nutrients and incident light energy are available.

Indeed, so profuse is the growth of algae that the pond contents are bright green in colour. The pond bacteria utilize this 'algal' oxygen to oxidize the organic waste matter. One of the major end-products of bacterial metabolism is carbon dioxide which is readily utilized by the algae during photosynthesis since their demand for it exceeds its supply from the atmosphere. Thus there is an association of mutual benefit ('symbiosis') between the algae and bacteria in the pond.

Since photosynthesis is a light-dependent activity there is a diurnal variation in the amount of dissolved oxygen present in the pond and a similar fluctuation in the level of the 'oxypause' (the point below the surface at which the dissolved oxygen concentration becomes zero) occurs. The pH of the pond contents also flows a daily cycle increasing with photosynthesis to a maximum which may be as high as 10. This happens because at peak demand algae remove CO_2 from solution more rapidly than it is replaced by bacterial respiration: as a result the bicarbonate ions present dissociate to provide not only more CO_2 but also the alkaline hydroxyl ion which increases the pH value:

$$HCO_3^- \longrightarrow CO_2 + OH$$

(b) Maturation Pond

Maturation ponds are wholly aerobic and are able to maintain aerobic conditions at depths of up to 3m. Maturation ponds are used as a second stage to facultative ponds. Their main function is the destruction of pathogens.

The removal of BOD_5 in maturation ponds is small: two ponds in series, each with a retention time of 7day, are required to reduce the BOD_5 from about 50-70 mg/l to less than 25 mg/l

(c) Anaerobic Ponds

These ponds are designed to receive such as high organic loading that they are completely devoid of dissolved oxygen. They are most advantageously used; to pretreat strong wastes which have a high solids content. The solids settle to the bottom where they are digested anaerobically.

The successful operation of anaerobic ponds depends on the delicate balance between the acid-forming bacteria and the metha-nogenic bacteria: thus a temperature greater than 15^0 C is necessary and the pond pH must be greater than 6. Under these circumstances sludge accumulation is minimal:

This type of pond has in the past been unpopular with design engineers because of the fear of odor release and the extra maintenance required.The relationship between odor development and organic loading is now reasonably well understood so that this problem can usually be overcome at the design stage.

(d) High-Rate Ponds

High rate ponds are designed to maximize algal growth and so achieve high protein yields. They are characterized by large area: volume ratios; depths are therefore shallow, 0.2-0.6m. The pond contents need to be mixed once or twice each day to resuspend any settled solids, and removal of the algae from the final effluent is essential.

(e) Advantages of Ponds

Some advantages of pond systems are:

(1) They can achieve any required degree of purification at the lowest cost and with the minimum of maintenance by unskilled operators.

(2) the removal of pathogens is considerably greater than that in other methods of sewage treatment.

(3) They are well able to withstand both organic and hydraulic shock loads.

(4) They can effectively treat a wide variety of industrial and agricultural wastes.

(5) They can easily be designed so that the degree of treatment is readily altered.

(6) The method of construction is such that, should at some future date the land be required for some other purpose, it is easily reclaimed.

(7) The algae produced in the pond are a potential source of high-protein food which can be conveniently exploited by fish farming.

2.5.3.d Aerated Lagoons

Aerated lagoons are activated sludge units operated without sludge return. Historically they were developed from waste stabilization ponds in temperature climates where mechanical aeration was used to supplement the algal oxygen supply in winter.

Aerated lagoons are now usually designed as completely mixed non-return activated sludge units. Floating aerators are most commonly used to supply the necessary oxygen and mixing power.

Aerated lagoons achieve BOD5 retention times(2-6d); retention times less than 2d are not recommended as they are too short to permit the development of a healthy flocculant sludge. They are often useful as pre treatment units before a series of ponds, particularly when used as a second stage of development to extend the pond capacity. In common with all activated sludge systems, aerated lagoons are not particularly effective in removing faecal bacteria: FC reductions are only 90- 95 percent and further treatment may therefore be necessary.

Organic waste is introduced into a reactor where an aerobic bacterial culture is maintained in suspension. The reactor contents are referred to as the mixed liquor. In the reactor, the bacterial culture carries out the conversion.

CHAPTER 3

CONCEPTS IN AQUATIC TREATMENT SYSTEM USING WATER HYACINTH

3.1. INTRODUCTION

Waste water applied to either natural or man made of wetlands (marshes, peat bogs, ponds, etc) for the purpose of treating the waste water is termed herein "aquatic treatment". Most aquatic treatment system consists of one or more shallow ponds in which one or more species of aquatic macrophytes like water hyacinth,(*Eichhornia Crassipes*).can be used to purify municipal and industrial waste waters when treatment facilities are designed to advantageously use the natural characteristics of these plants.

The shallower depths and the presence of aquatic macrophytes in place of algea are the major differences between aquatic treatment system and stabilization ponds, and are of conceptual significance since the effluent from aquatic systems is of higher quality than the effluent from stabilization pond systems, The purpose of this literature review is to present a review of current thinking on the mechanisms involved in and the rational design of aquatic treatment system.

3.2. ADVANTAGES OF WATER HYACINTH POND SYSTEM

The conventional biological treatment methods employing trickling filters or activated sludge process, are very expensive to install as well as to run. The past experience with such treatment plants shows that many of them are either performing poorly due to the lack of skilled operational supervision or became idle because of mechanical breakdown and lack of maintenance. A few of them again were not designed properly. On the other hand this system is simple to construct, have the least amount of mechanization and require little or no skilled supervision for operation. The design criteria for such low cost system has been evolved through out the world. An extensive study conducted under certain conditions the degree of treatment that can be achieved is as good as that of the conventional systems, if this low cost treatment system is adopted.

Water hyacinth on the sewage pond prevents the rolling by the wind action and reduces offensive odor releases. Also water hyacinth ponds system requires less time for the treatment of sewage and produces better effluent quality than other ponds system Thus sewage treatment with water hyacinth pond system is considered to be advantageous than other system.

3.3 PLANT CHARACTERISTICS

The water hyacinth is commonly found in water ways in tropical and semitropical areas around the world. It grows through out Bangladesh. It is usually free-floating, obtaining nutrients from the water. The individual plants measure from 19.7in-47.2 in. (0.50 m-1.20 m) from root tip to the top of the flower cluster when grown in the waste water. This corresponds to a standing crop ranging from 44.6 ton/acre-182.9 ton/acre(100 metric Ton/ha-410 metric ton /ha)(wet weight). Approximately 95% of the weight of the plant tissue is water.

The composition of water hyacinth removed from a treatment system will provide an initial estimate of the nutrient removal potential of these plants. These characteristics are summarized in Table 3.1.

TABLE 3.1 Dry weight of whole water Hyacinth Plants Grown in Waste water(Wolverton and McDonald, 1978).

	Dry Weight as a percentage	
	Average	Range
Crude protein	18.1	9.7-23.4
Fat	1.88	1.59-2.20
Fiber	18.6	17.1-19.5
Ash	16.6	11.1-20.4
carbohydrate (computed by mass balance)	44.8	36.9-51.6
Kjeldahl nitrogen (as N)	2.90	1.56-3.76
Phosphorous (as P)	0.63	0.31-0.89

Use of the values given in Table 3.1 will give a conservative estimate for nutrient removal by hyacinth systems. This information can be used to provide order of magnitude estimates applicable to treatment systems which harvest only the plant tops by mowing the crops.

The water hyacinth plants, themselves, bring about very little actual treatment of the waste water. Their function is to provide the components of the aquatic environment that improve the waste water treatment capability and/or reliability of that environment. 'some specific functions of plants in aquatic treatment systems are presented in Table 3.2.

TABLE 3.2 Function of Aquatic plants in Aquatic Treatment Systems(Walter, 1981).

Plant parts	Function
Roots and /or stems in water column	1. Surfaces on which bacteria grow. 2. Media for filtration and adsorption of solids.
Stems and / or leaves at or above water surface	1. Attenuate sunlight and thus can prevent growth of suspended algae. 2. Reduce effects of wind. on water (e.g, roiling of settled matter). 3. Reduce transfer of gases and heat between atmosp here and water.

3.4 SYSTEM BIOLOGY

A generalized diagram of the process that occur in water hyacinth ponds is shown in Figure.3.1.

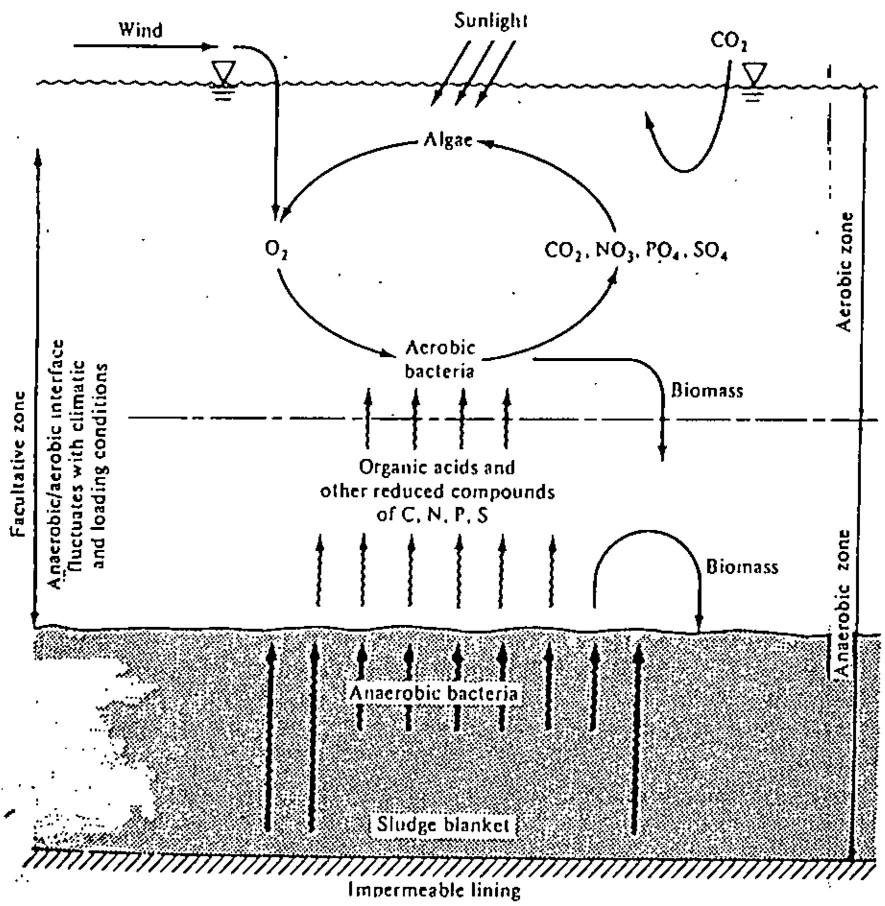

Figure 3.1 General diagram of facultative pond reaction(Source: Howard P, 1985).

Aerobic conditions are maintained in the upper portions of the pond by oxygen generated by water hyacinth to a lesser extent and by penetration of atmospheric oxygen. stagnant conditions in the sludge along the bottom prevent oxygen transfer to that region and anaerobic conditions prevail there. The boundary between the aerobic and anaerobic zones is not stationary. Mixing by wind action and penetration by sunlight may extend the aerobic area downward. Conversely, calm waters and weak lighting result in the anaerobic layer rising towards the surface. Diurnal changes in the light conditions may result in diunal fluctuations in the aerobic-anaerobic interface. The volume through which the presence of dissolved oxygen fluctuates is called the facultative zone. Because organisms in the zone must be capable of adjusting their metabolism to the change in oxygen conditions.

Considerable interaction exists between the zones. Organic acids and gases, products of decomposition in the anaerobic zone, are released and became soluble food for organisms in the aerobic zone. Biological solids produced in the aerobic zone ultimately settle to the bottom where they die, providing food for the anaerobic benthic organisms.

Climate plays an important role in the operation of ponds. Within naturally occuring temperature ranges, biological reactions roughly double for each 10^0 C increment in water temperature. When water temperature drops to near freezing, biological activity virtually ceases.

3.5 GROWTH RATE OF WATER HYACINTH

Growth rate of water hyacinth is rapid in tropical region. It doubles in mass about every 6 days. Productivity is also affected by the temperature. It is best suited in hot climates.

Although water and orthophosphorous concentrations are two important factors controlling water hyacinth growth based on the scientific literature, flow and velocity, substrate and light are key factors governing growth rate. There is no doubt that the input of macro nutrients (N,P) promotes the plants growth in aquatic systems where they were previously absent (or only present in small numbers).

In tropical fresh waters, plant nutrients are often the factors most likely to limit plant growth and thus the addition of nutrients to the system often produces spectacularly rapid results.

For the growth of water hyacinth, plant nutrients are constantly in demand and thus are adapted to respond rapidly to nutrients as they became available.. Growth also varies with the type of organic matter available in waste water.

3.6 SURVIVAL CONDITION OF WATER HYACINTH

As stated earlier that water hyacinth can not grow in an area without a suitable substrate. But in waste water with high organic content, low PH and redox potential, high concentration of organic acids, water hyacinth growth is significantly inhabited. The inhibitory property is associated with high concentration of soluble organic compounds in the interstitial water. waste water receiving refractory organic matter retained growth-inhibiting properties for longer than those receiving labile organic matter.

A wide range of soluble organic compounds, some from the anaerobic decomposition of cellulose and lignin, are toxic to plants. These compounds, plus other potential phytotoxins (metals gases, and dissolved sulphides) in anaerobic sediments, produce a seemingly hostile environment for plant growth.

The survival of the plant under the stress of pollution in waste waters and brackish water depends on the concentration of pollutants and time of contact. In order to use water hyacinth for pollution control, the tolerance index and the maximum absorption capacity for a pollutant are important factors.

The term tolerance index referred to the uptake of metal ions in the experiments conducted by S. Z. Haider, K.M.A Malik and M M. Rahman. The limit to the uptake of metal ions has been expressed in terms of the Tolerance Index (TI) of water hyacinth and has been defined as
TI =a/b 100/w Where,

a= amount absorbed from polluted water after time 't'
b= amount already absorbed in controlled experiment (blank) after time 't'.
w= weight of water hyacinth in kg.

The determination of TI of water hyacinth indicates the survival pattern under adverse conditions of heavy pollution since it involves a mechanisms which enables the plant to deal with the toxic concentrations of metals and other chemicals. The TI of water hyacinth has been found to vary between 15 to 45 for various metals under the maximum absorption conditions. Some results are shown in Table.3.3.

Table.3.3. Tolerance index of some metals ions for water hyacinth(Haider and Malik 1981).

Metal	Maxm. Conc (mg/l)	TI
Cr	8.0	15
Cu	7.0	31
Ni	6.5	23
Zn	12.0	45
Fe	5.7	27
Mn	6.9	26

Thus it may be necessary to replenish some nutrients for water hyacinth used for pollution control in order to maintain the ionic balance in the plant for its survival and effective use for longer duration.

3.7 POLLUTANTS REMOVAL BY WATER HYACINTH

3.7.1 General: water hyacinth (*Eichornia Crassipes*) can remove a wide variety of pollutants from waste (includes sewage also). It can take up large amounts of inorganic nutrients (especially N and P) and heavy metals (such as Cd, Cu, Hg and Zn) as a consequence of the growth requirements and decreases the concentration of algal cells through light shading by the leaf canopy. Nitrogen and phosphorous reductions up to 80% have been achieved.

Water hyacinth has also been found to reduce the amount of dissolved solids in polluted water. A comparative study indicates that there is about 87% reduction of the suspended solids in presence of water hyacinth in 6 days whereas only 25% of the dissolved solids are reduced by standing without water hyacinth during the same period.

The basic function of the water hyacinth in the pollutant removal mechanism is to assimilate, concentrate and store pollutants on a short-term basis. subsequent harvest of the plant bio mass results in permanent removal of stored pollutants from the pond treatment system.

The nutrient assimilation capacity of water hyacinth is directly related to growth rate, standing crop and tissue composition. The potential rate of pollutant storage by water hyacinth is limited by the growth rate and standing crop of bio mass per unit area. water hyacinth was found to reach a standing crop level of 30 tones (dry weight)/ha in Florida, resulting in a maximum storage of 900 kg N/ha and 180 kg P/ha (Reddy and De Busk 1987).

3.7.2 Removal Mechanism

The mechanisms by which pollutants common in wastewater are reduced in water hyacinth systems are considered in the following sections.

3.7.2.a :BOD Removal:

In this systems the BOD (bio-chemical oxygen demand) associated with settleable solids in a waste water is removed by sedimentation. The colloidal/soluble BOD remain in solution is removed as a result of metabolic a activity by micro-
organisms that are :

(1) Suspended in the water column:
(2) Attached to the roots and stems of the plants.
(3) Attached to the sediments.

3.7.2.b Solids Removal :

This system has long hydraulic residence times. Generally several days or longer conceptually,
virtually all settleable and floatable solids of waste water origins are removed by sedimentation. Conceptually, hyacinth systems are slow rate, horizontal flow sedimentation basin.Horizontal flow sedimentation is a gravity separation process in which a settling basin provides a quiescent environment that enables particles of specific gravity greater than water to settle to the bottom of the basin. In addition water hyacinth acts as a filter media for the floating materials. Also the roots

of water hyacinth influences the settling velocity of particles which ultimately affects the removal efficiency. The process of removal will be clear from Figure 3.2.

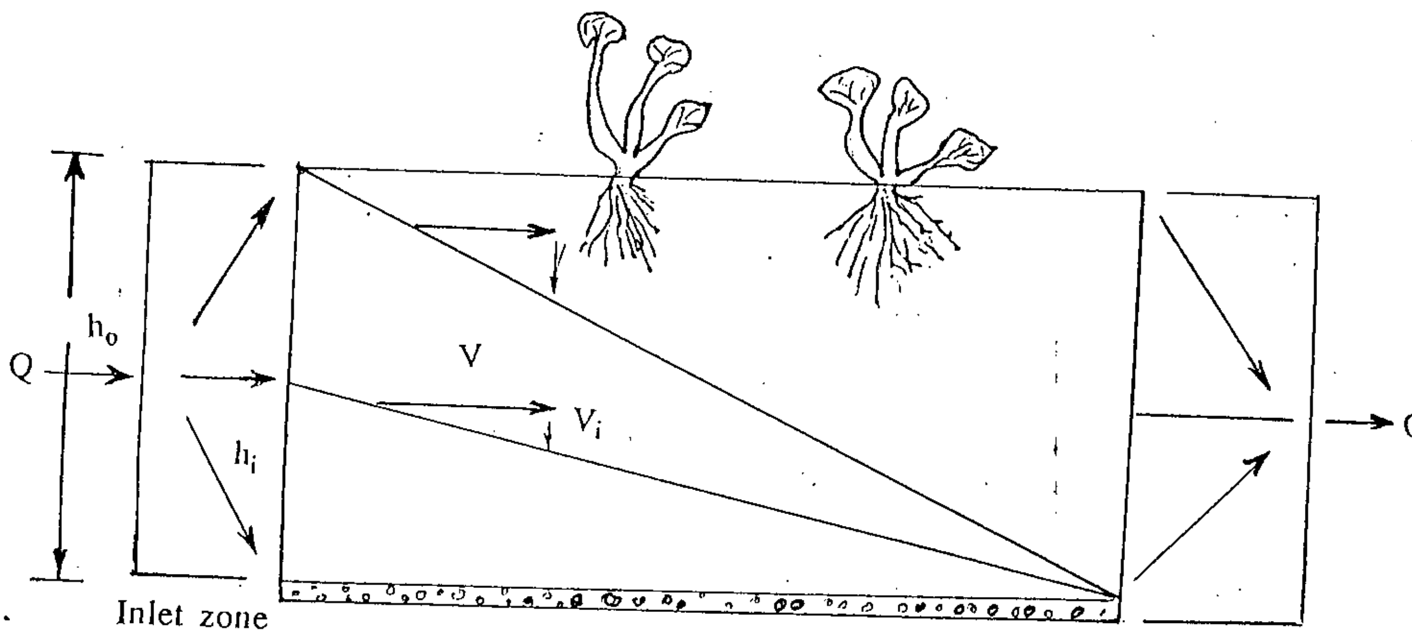

Fig. 3.2 Solids removal mechanism in sedimentation basin.

As shown in Fig. 3.2 a unit of water entering the ideal sedimentation basin at the left is assumed to spread out uniformly over a vertical plane AA. Assuming that all particles settle descretely and that those which strike the bottom are removed, the absolute velocity path V represents the maximum elevation where particles of the smallest settling velocity V_0 which enters the basin at the water surface (at height h_0 above the bottom) will travel along the path V and be removed just as the water moving at velocity V enters the outlet zone.

All other particles of the same settling velocity will follow parallel paths and be removed near the inlet end of the basin. Particles with settling velocities V_i less than V_0 will follow an absolute path parallel to V. Consequently, they will be carried over the outlet if they originate above h_i or be removed if they enter the tank at a lower elevation.

It has been seen that over flow rate is independent of the depth of the basin and the percentage removal experienced by a class of particles with settling velocities V_i smaller than V_0 will equal $100V_i/V_0$.

As the velocity components Vi increases due to strike of particle with roots, the removal efficiency also increases in case of water hyacinth system.

Nonsettling/colloidal solids are removed, at least partially, by bacterial growth (which results in the settling of some colloidal solids and the microbial decay of others) and collisions (inertial and brownian) with and adsorption to other solids (plants, pond bottom, suspended solids, etc)

3.7.2.c Nitrogen Removal :

Nitrogen and phosphorous compounds are key nutrients for growth in living systems, and in biological treatment processes where there is a; net production of bio mass, a certain amount of these materials is removed by assimilation into the biomass. Nitrogen compounds can also be removed by non-assimilative biological processes which have been utilized to provide the principal means of biological nitrogen removal. Before discussing the major nitrogen conversion and removal processes in detail, it will be helpful to review the forms in which nitrogen can exist in the environment .

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a. Forms of Nitrogen: Nitrogen in waste water can exist in four forms: organic nitrogen, ammonia nitrogen,nitrite nitrogen and nitrate nitrogen are the principal forms in untreated wastewater. In nature, in the nitrogen cycle, organic nitrogen and ammonia nitrogen are converted first to nitrite and then to nitrate. The nitrogen may be bound in complex organic molecules. organic nitrogen may be biologically converted to free ammonia ($NH3^0$) or to the ammonium ion (NH^+) by one of the several different metabolic pathways. These two species together termed ammonia nitrogen exist in equilibrium according to the following relationship:

$$NH4^+ \longrightarrow NH3 + H^+$$

Ammonia nitrogen, the most reduced nitrogen compound found in wastewater,will be biologically oxidized to nitrate as follows if molecular oxygen is present .

$$NH_4+ +3/2O_2 \longrightarrow NO_2- +2H+ +H_2O$$

$$NO_2- +1/2O \longrightarrow NO_3-$$

These reactions result in the utilization of about 4.6 mg of O_2 per each mg of NH_4+-N oxidized with about 7.1 mg of alkalinity needed to neutralize the acid (H^+) produced.

b. Operations and processes for the Removal of Nitrogen

Over the past 50 years, a number of operations and processes have been used for the conversion and removal of nitrogen from waste water. Biological treatment process is still one of the most economical for nitrogen removal from waste water. Aquatic treatment is common in biological process.(Metcalf and Eddy. 1979).). Nitrogen is removed from waste water during aquatic treatment by a number of mechanisms:

(1) Uptake by and subsequent harvesting of plants:
(2) Volatilization of ammonia: and
(3) Bacterial nitrification/denitrification.

Of these, bacterial nitrification/denitrification appears to have the greatest nitrogen removal potential. Nitrifying bacteria grow readily on the submerged portions of aquatic plants. Denitrification occurs in the sediments of aquatic systems. The mechanism of nitrogen removal by nitrification and denitrification is described below.

Nitrification-denitrification: Ammonia nitrogen can be converted to gaseous nitrogen, (N_2), by biological processes. while some ammonia is assimilated into bio mass in biological treatment systems, the most significant biological process for ammonia removal is bacterial oxidation of ammonia to nitrite and nitrate, called **nitrification.**

Nitrification provides the energy source for the aerobic autotrophic nitrifying bacteria, and very much more ammonia is consumed by this process in the growth of nitrifying bacteria than by incorporation into organic nitrogen in the resultant bio mass. It should be noted that, while nitrification removes ammonia, it does not remove nitrogen, but converts it to a different form.

Nitrite and nitrate, produced by nitrification or present in the original waste water, can be removed by microbiological reduction to nitrogen gas. this process is called '**denitrification**' and takes place in anoxic conditions where certain micro-organisms use nitrite and nitrate as an alternative source of oxygen, a process called dissimilation. Since the product of denitrification is a nonpolluting gas released from the aqueous phase, denitrification is a true nitrogen removal process. Successive biological nitrification and denitrification thus forms a mechanism for the complete removal of nitrogen in the form of ammonia, nitrite and nitrate from an aqueous waste.

Microbiological oxidation of ammonia and ammonium ions is effected by different species of chemo-autotrophic bacteria in two stages. The first stage is the oxidation of ammonium ions to nitrite, sometimes referred to as '**nitrosification**.

$$NH4 + 1.5\ O2 \longrightarrow NO2 + 2H + H_2O \quad \_\ 58 to\ 84\ kcal$$

The organisms carrying out this process are generally considered to be *Nitro somonas europea* and *monocellla* and *Nitrosococcus*. Other organisms that have been postulated are *Nitrosospira,Nitrosogloea,* and *Nitrosocystis* though the existence of these organisms has been the subject of some controversy. In the second stage, nitrite is oxidized to nitrate

$$NO2 + 0.5\ O2 \longrightarrow NO3 \quad \_\ 15.4\ to\ 20.9\ kcal$$

Organisms generally recognised as carrying out this process are *Nitrobacter winogradskyi* and *Nitrocystis*, and other postulated organisms are *Nitrococcus, Nitrospina Nitrobacter agilis*. The existence of *Nagilis* as a species distinct from N *winogradskyi* has also been the subject of some controversy. A review of the ecology of nitrifying bacteria has been presented by Besler (1979).

Two important points are demonstrated by equations above .Firstly, nitrification requires a high oxygen input, about 4.5 kg oxygen for each kg ammonium-nitrogen. Secondly, the first stage of nitrification produces acid, so that the pH of a waste water will tend to fall during nitrification. In an uncontrolled system containing sufficient ammonia, The pH will eventually fall to a level where nitrification stops. The production of what is effectively a dilute solution of nitric acid by microbiological nitrification has been used to advantage in the utilization of treated sewage effluent as power station cooling water(Humphris, 1977). The sewage effluent provides a cheap source of cooling water which is passed through a biological nitrification stage before use.

Denitrification occurs in the absence of dissolved oxygen when the nitrates formed earlier are reduced to nitrogen gas and given off to the atmosphere. For denitrification to occur, prior nitrification is essential. Also a low carbon content is essential for the previous nitrification step.

3.7.2.d Phosphorous Removal

The phosphorus removal potential of water hyacinth systems is variable and transitory. The major phosphorus removal mechanisms are plant uptake and biological and chemical storage of phosphorus in the sediments.

Haider (1984) stated the fact that it is possible that the metal ions, molecular species and anions are metabolized in presence of oxygen and respiration energy since acetates, formates, phosphates, carbonates, nitrates, phenols etc, are readily consumed giving the plant accelerated growth. particularly phosphates are stored in plant tissues and about 60% more phosphorus became concentrated in the leaves of water hyacinth and stems than in root. Phosphorous, which is removed from the waste water with the excess sludge, is assimilated by bacteria. These bacteria remains attach with the roots of water hyacinth.

The basic principle of removal in this process is shown in Figure 3.3. The bacteria are exposed alternatingly to anaerobic and aerobic conditions. Certain bacteria, notably *Acinetobacter*, poses the ability to absorb low molecular weight organics under anaerobic conditions.Then energy required for this is made available by the release of phosphorus bound as phosphates in volutin granules in the protoplasm of the bacteria. Under subsequent exposure to aerobic conditions, the organic matter is oxidized and energy is made available for growth and for the reaccumulation of phosphates into polyphosphates in the bacteria. The net effect is an excess content of phosphorus in the bacteria possessing this ability. These bacteria have a competitive edge over other bacteria, since they can hold the readily available organic matter for their own consumption. Under proper process conditions, they can flourish and dominate the population resulting in an increased P content in the waste sludge. Ultimate disposal of phosphorus from hyacinth systems will be by:

(1) Harvesting plants:

(2) Dredging the sediments .

(3) Resolubilizing phosphorus stored in the sediments and releasing it to the receiving water when it will have the least environmental impact.

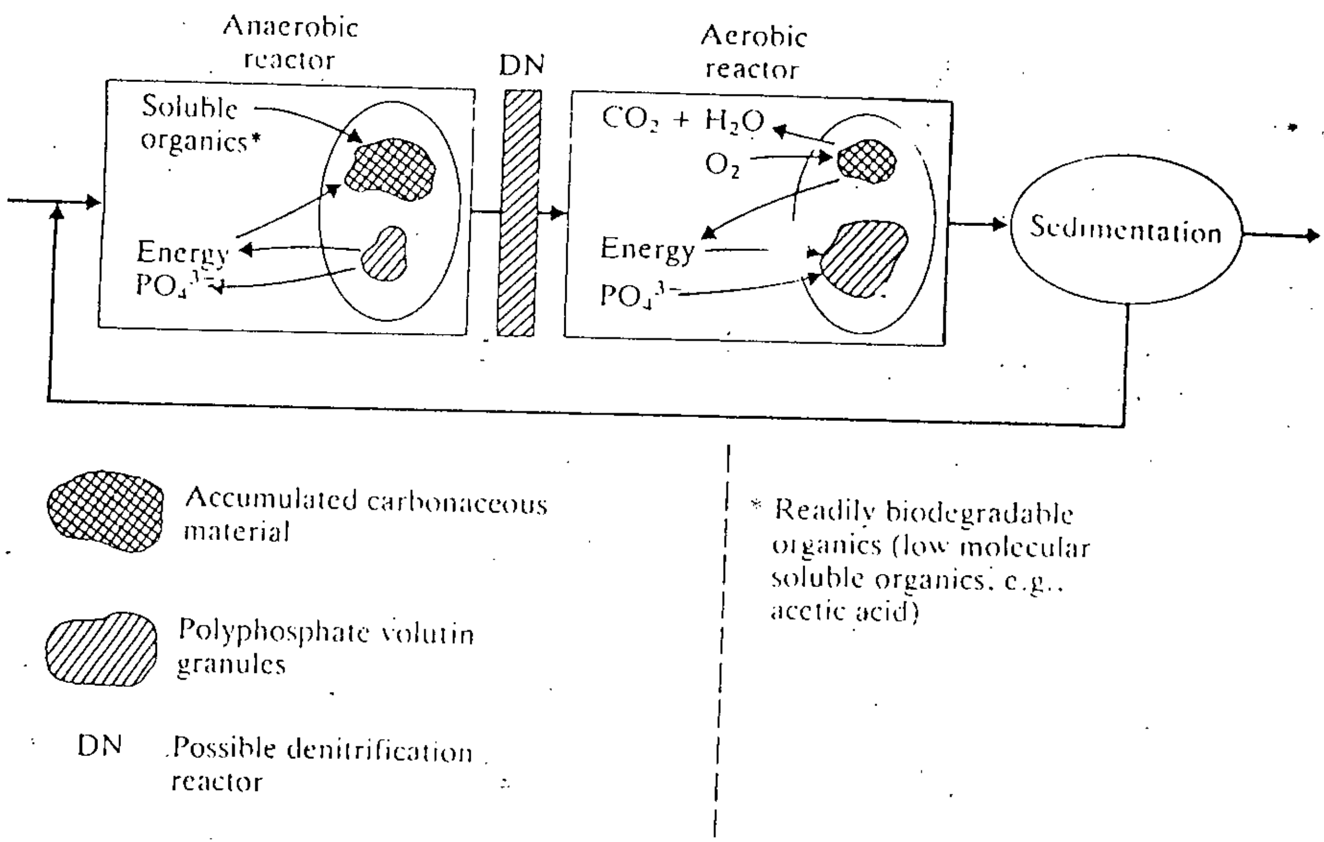

Fig3.3 Biological release and uptake of phosphate.(Tehbnoglous, 1985).

3.8 COST OF WATER HYACINTH TREATMENT SYSTEM

The economic incentive for including water hyacinth ponds in a waste water treatment facilities is very attractive under favorable conditions. Comparative cost estimates for 1 mgd (3785 m^3/day) plants designed to achieved advanced secondary and advanced waste treatment has been described by crites. The following data are a comparison of total costs of alternative methods(treatment system)for achieving advanced wastewater treatment [plant capacity:1 mgd (3785 m3/day)]

(1) Overland flow plus hyacinths _79$/1000 gal (per 3.785m3) :

(2) Slow rate land treatment _110$/1000 gal (per 3.785m3):

(3) Conventional advanced waste treatment_240$/1000 gal (per 3.785 m3). (The cost includes amortized capital, operation, maintenance, and land)

The hyacinth system considered in the preceding data consists of preliminary screening and grit removal, chemical addition of alum or ferric chloride, an land treatment facilities, and water hyacinth ponds. Harvested hyacinth are composted. The conventional advanced waste treatment system consists of activated sludge, chemical precipitation of phosphorous, biological nitrification followed by denitrification, and mixed media filtration.

The hyacinth system considered in Table .3.4 consists of preliminary screening and grit removal followed by conventional oxidation ponds and hyacinth ponds operated in series. The harvested hyacinth are composted and sold or given away. The conventional advanced secondary treatment system consists of activated sludge followed by dual media filtration

The costs given in Table 3.4 and the preceding data are based upon standardized estimation techniques keyed to March 1978 U.S.A national indices. The relatively broad range shown in these estimates clearly indicate that water hyacinth systems are worthy of serious consideration in small treatment facilities. Less extensive analyses indicate that the cost advantages of water hyacinth systems continue to be favorable for treatment facilities with hydraulic capacities up to at least 10 mgd (37850m^3/day).

Table 3.4: Comparison of Total Costs, Alternative Methods for Achieving Advanced Secondary Treatment.(Crites, 1979).

Treatment system (1)	Total cost, in cents/1000 gal (cents/3,785m^3) Favorable Conditions (2)	Less favorable conditions (3)
Oxidation pond plus hyacinths	45	74
Overland flow land treatment	96	115
Conventional advanced secondary treatment	130	130

[a]Cost includes amortized capital, operation, maintenance, and land.
Note: Plant capacity: 1 mgd (3,785m^3/day)

The hyacinth system considered in Table .3.4 consists of preliminary screening and grit removal followed by conventional oxidation ponds and hyacinth ponds operated in series. The harvested hyacinth are composted and sold or given away. The conventional advanced equipment, and energy necessary to treat waste water if the major stimules for research and design of hyacinth treatment systems. The results of a preliminary economic analysis comparing the costs and energy utilization of aquatic and conventional systems are presented in Table.3.5

Table.3.5 Costs and Energy Utilization of Conventional and Aquatic Treatment Systems(Tchobanoglous, 1979).

Item	PLANT SIZE, in millions of gallons per day					
	0.1		0.5		1.0	
	Conven- Conven-tional*	Aquatic** Aquatic	tional	Conven-	tional	Aquatic
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Capital cost, in dollars X 10^{-6}	0.71	0.37	1.23	0.55	1.60	0.90
O&M cost, in dollars per year X10^{-3}	35	21	78	48	117	74
Energy, in British thermal units per year X 10^{-9}	0.88	0.51	3.15	1.20	4.80	2.08

*Activated sludge + chlorination.

*Primary clarification + artificial wetlands + chlorination.

3.9 DESIGN OF AQUATIC TREATMENT SYSTEM

Design concepts for aquatic treatment systems differ some what from those for conventional systems. The aquatic environment or series of environments necessary to achieve the desired level of waste water treatment must be envisioned. The type of plants(water hyacinth) to maintain these environment must be selected. The effects of climatic and environmental factors on the aquatic treatment process must be anticipated and mitigating measures taken as necessary.

3.9.1 Factors affecting design of aquatic treatment system

The factors which may have fnfluences in the design of an aquatic system are discussed in the following sections.

3.9.1.a climatic influences

A Consequence of the larger surface areas and longer hydraulic residence times of aquatic system is greater sensitivity to climatic factors such as temperature, rain and wind. Air temperature (as it affects both plant survival and water temperature) has a significant affect on aquatic systems performance. Rain storms can result in hydraulic overloading of an aquatic system causing wash-through of BOD and resuspension of settled matter. High winds will cause roiling of settled matter and may damage the plants to an extent that they will not function as intended by design.

Temperature affects the metabolic rates of plants and bacteria dramatically. Thus, the rates of pollutant removal mechanisms dependant on biological activity, either directly or indirectly, will also be a function of air and water temperature. Therefore, Aquatic treatment system, in which these mechanisms are to be functional will have to be larger in winter than summer to achieve the same level of treatment for a given pollutant loading. At water temperatures approaching 0^0c, metabolic activity virtually ceases: thus,wastewater treatment would result only from physical/chemical mechanisms. This reduced level of treatment may be inadequate in some situations. In these cases aquatic treatment would have to be considered a seasonal treatment process.

Additional aspect of winter low temperatures is that they may cause the plants to become dormant or die. Either even may, but not necessarily, result in loss of bacterial support structure or leakage of plant contained compounds. Research in this area is necessary.

3.9.1.b Environmental Factors

Environmental impacts that could result from the presence of an aquatic treatment system includes odors, fog generation, increased disease vector organism populations, and introduction of nuisance organisms to the local environment. The potential for significant environment impact from any of these or other factors must be evaluated and mitigating measures taken as necessary. The potential mosquito nuisance caused by an aquatic system may be the most difficult to mitigate. while numerous researchers have reported control of mosquitoes once mosquito fish (*Gambusia* spp) were introduced to the aquatic system, california public health vector control officials have not considered this level of control adequate in general.

The potential of the local environment to have significant impact on the organisms in the aquatic system must also be evaluated. Of particular concern in this regard are:

(1) Local and migratory animals that may eat plants, damage levees or blocking flow etc.

(2) Local plant diseases or plant - consuming insects.

As an example, the waste water treatment potential of water hyacinth aquatic systems may be reduced in areas where biological control of hyacinths has been established.

3.9.1.c Wastewater characteristics

pollutant concentrations in domestic waste waters should not be toxic to aquatic plants in properly designed treatment system. If an appreciable portion of the waste water is of industrial origins, small-scale: pilot studies should be conducted to evaluate the toxicity of the waste water.

3.9.1.d Process Reliability

The greater influence of climatic and other environmental factors on aquatic processes should reduce their reliability in comparison to conventional processes. However, the slower rate of treatment, reduceed reliance on equipment, and greater bacterial diversity of aquatic processes should improve their reliability, comparatively. Properly designed aquatic systems appear to be as reliable as conventional systems for the removal of BOD, SS and nitrogen compounds assuming the .reduced rate of treatment during winter is accounted for in the design.

Aquatic systems are comparatively insensitives to spikes in influent wastewater quality. Because of the pond-like nature of aquatic systems, even if the aquatic treatment processes fail completely, the effluent should be comparable in quality to effluent from stabilization pond systems. From a theoretical consideration, factors critical in the rational design of an Aquatic system in which a significant reduction in BOD is to occur are :

(1) An accurate partitioning of influent BOD into that which will settle and that which will remain in solution:

(2) Providing sufficient structure in the form of plant roots or stems to support the bacterial population necessary to reduce the solution BOD concentration to the desired level :

(3) Keeping the BOD loading rate sufficiently low and distributed to prevent anaerobic conditions at or sufficiently close to the water surface to cause odors or other aesthetic nuisances: and

(4) taking measures as necessary to maintain required BOD reductions throughout the year, particularly during the winter when bacterial and plant metabolic rates are low and both the

quantity of bacterial support structure and the oxygen flux into the aquatic system may be reduced.

Information necessary to consider each of these factors in the rational design of an Aquatic system to remove BOD would include:

(1) The BOD removed with settled solids as a function of pretreatment (raw, primary, secondary, or lagoon).

(2) The release of soluble BOD from settled solids as a function of solids type (primary, secondary, or algal) and water temperature and DO (dissolved oxygen concentration).

(3) The leakage of soluble BOD from the aquatic plants as a function of plant variables (species, density, and growth phase) and water temperature and DO.

(4) The soluble BOD reduction effect of bacteria in the water column and on the bottom detrital layer as a function of BOD concentration, water temperature and DO, and the nature of the detrital layer (i.e, solids type and loading as well as the plant species being grown).

(5) The BOD reduction effect of bacteria attached to plant roots or stems as a function plant variables, BOD concentration, and water temperature and DO.

(6) The heat flux between the water and atmosphere as a function of plant variables and climatic conditions.

(7) The oxygen flux into the water from the atmosphere as a function of plant variables.

(8) The net oxygen flux to the water via the plant root system (as measured by changes in water quality) as a function of plant variables and water quality.

(9) The hydraulic characteristics of aquatic systems as a function of plant variables.

(10) The localized loading that will cause odors or avoidance responses by predators of mosquitoes.

3.9.2 Design of aquatic treatment system

Aquatic macrophytes can be used in single cell ponds in series pond systems, in ponds providing tertiary treatment following conventional secondary treatment, and in completely-integrated facilities.

The depth of the hyacinth ponds and the frequency of plant harvesting will determine whether the process will be used to provide advanced secondary or tertiary treatment. Maximum nutrient removal is achieved in shallow ponds which are harvested frequently. The depth of the hyacinth ponds and the frequency of plant harvesting will determine whether this process will be effective or not. Maximum nutrient removal is achieved in shallower ponds which are harvested frequently.

Preliminary results reported from two facilities in Florida indicate that a final effluent can be produced which will meet advanced waste treatment standards for BOD_5, TSS and total nitrogen (TN), but will not meet phosphorous standards. Other design criteria is described in the following sections:

3.9.2.a. BOD Removal

Aquatic treatment systems are capable of producing effluents with BOD_5 concentrations consistently below 10 mg/L, as is evident from the average effluent BOD concentrations reported for 24 different studies. Based in these emperical data it appears that aquatic systems using waterhyacinth plants could be designed at BOD_5, loading rates up to approx 100lb/acre.day (110 kg/ha,day) with 80% or more of the applied BOD being removed (BOD removal rates would be less during winter if the waste water cools appreciably).

The surety of achieving low effluent BOD concentrations is increased by reducing the loading rate. However, regardless of the loading rate, the effluent BOD_5 concentration will not be much below 5 mg/L because of the leakage of organic matter from the aquatic plants. Others have recommended BOD_5 loading rates of 50 lb/acre.day (30kg/ha.day)_125 lb/acre.day (140 kg/ha.day) or more for water hyacinth systems. The BOD removal rates (thus, loading rates) of aquatic systems could be increased by supplementing the natural wet land environment with additional oxygen (i.e, aeration) and bacterial support structure or by reducing heat loss from the system during winter. The cost effectiveness of these types of supplemental facilities would have to be determined on a case-by-case basis.

The BOD load to an ATU should be applied in such a manner as to not cause either hydraulic short-circuiting or aesthetic problems. Short-circuiting can be prevented by designed ATU's to have either geometric with large length (the direction of flow) to width ratios or manifold influent and effluent structures that distribute waste water flow across the wetlands uniformly. A length-to-width ratio for ATU's of at least three has been recommended.

Considering that the surface area requirement of aquatic systems designed to meet secondary requirements is related to the BOD applied, in many cases it will be cost-effective to reduce the BOD of raw sewage by conventional or other alternative treatment processes before applying it to the wetlands. The most probable candidates for this role are primary clarification, an Imhoff tank, or various types of lagoons.

3.9.2.b Depth

Optimal depths for ATU's as a function of wastewater quality and the plant species grown have not been determined. When floating water hyacinth are used water depth can be increased without harming the plants. In these cases increasing water depth increases hydraulic residence time (and construction costs) but decrease the plant root/wastewater inter association once the water depth becomes greater than the depth of the root penetration. Increasing residence time and decreasing root/wastewater contact are off-setting in terms of wastewater treatment. Therefore, from a cost standpoint, shallower water depths should be used.

Once the bulk of the wastewater solids have been removed, depth ofATU's containing floating plants should be such that there is approximately 8 in (200 mm) of "clear" water between the root zone (water containing plant roots) and the settled matter on the bottom of the ATU.Thus, a "secondary" water hyacinth system (one designed to meet secondary standards) should have a water depth of approx 12 in. (300 mm): 4 in. (100 mm) of root zone plus 8 in/(200 mm) of clear water. A secondary water primrose system should have a water depth of approx 32 in. (810 mm) of root zone plus 8 in. (200 mm) of clear water. A water hyacinth ATU designed to achieve an advanced level of treatment may have a water depth of 18 in. (460mm) or more (through this depth should decrease to about 6 in. (150 mm)in the vicinity of the outflow structure to maximize effluent water quality. This increase in depth is a reflection of the fact that hyacinth roots are longer in waters of higher quality. Water depths recommended by others for secondary hyacinth systems have ranged from 1.5 ft-5 ft (0.5m-1.5 m). In support of the shallower depth notion, an observation of the Disney World secondary hyacinth system has been that for the same flow, a 14 in (360mm) water depth results in a slightly, though not significantly, better effluent than a 36 in (910 mm) water depth.

3.9.2.c Solids Removal

Aquatic systems are capable of producing effluents with SS (suspended solids) concentrations consistently below 10 mg/L as is evident from the average effluent SS concentrations reported from 16 different studies. Aquatic systems are also effective at removing algal solids from stabilization pond effluents. SS removal and distribution (to avoid localized problems caused by solids build-up) occurs incidental in the design of the ATU in most wastewater treatment situations because of the influent distribution system necessary to keep localized BOD loadings low.

The major design concern with regard to settleable solids is how the solids should be handled/stored once they have settled from solution. The annual build up of solids in aquatic systems not receiving appreciable loads of settleable solids has been observed to be small, making frequent cleaning of the ATU's should be designed with essentially flat bottoms (include some slope for drainage) and levees having additional "free-board" so that as solids do accumulate on the ATU bottom the water level can be raised: and, thus, the design water depth in the ATU can be maintained over prolonged periods of operation. In cases where significant quantities of solids will settle from solution in the immediate vicinity of the inflow structure (as determined by either application of conventional sedimentation theory or sediment tatin studies). The depth of the ATU in the zone of heavy sedimentation should be sufficient to contain the solids that will accumulate between clanging. These solids storage pits or trenches within an ATU could be cleaned by vacuum dredging or by draining the ATU and using modified earth moving equipment to remove the solids.

Other solids related design considerations include preventing the growth of suspended algae, minimizing the effect of wind on SS removal performance, and pretreating wastewaters containing appreciable quantities of floatable matter (e.g., grease and oil).

Suspended algae growth is prevented by designing the ATU to have uniformly distributed plug-flow hydraulics and/or an adequately dense stand of floating water hyacinth.. An 80% coverage of the water surface with water hyacinths is reported to prevent the growth of suspended algae. Though the aquatic plants in an ATU diminish the effects of wind on the treatment process, high wind will cause some roiling of settled matter. The release of temporarily roiled waters from an aquatic system can be avoided by providing emergency storage capacity in or upstream of the ATU's so that discharge from the system can be stopped for sufficient time to settle the resuspended solids. Floatable matter introduced to an aquatic system:

(1) Rise to the water surface and there blocks oxygen transport into the water from the atmosphere:

(2) exerts an additional oxygen demand in the aerobic zone of the ATU: and

(3) may tend to cause odors.

For these reasons measure should be taken to remove floatable matter from wastewaters prior to aquatic treatment.

For an ATU to be designed rationally with regard to SS removal and solids storage it would be necessary to know the sedimentation and net accumulation rates of the various types of aquatic plant and waste water solids as a function of water quality.

3.9.2.d Nitrogen Removal

Harvesting plants to remove nitrogen is inefficient. Assuming most favorable conditions, the maximum nitrogen removal rate of this mechanism is only approx 5 lb/acre. day (6 kg/ha.day). To achieve this, approx 1 ton (900 kg) of plant bio mass would have to be harvested per acre.day (0.4 kg/ha.day). This could represent a significant solid waste handling and disposal problem.

Appreciable quantities of nitrogen as NH_3 (ammonia) can be removed from wastewater by volatization of NH_3 to the atmosphere. This requires raising the pH to 8 or more as a result of CO_2 uptake by submerged plants during photosynthesis. The nitrogen removal potential of this mechanism is seasonal and inconsistent (particularly if algae are the submerged plant) and can best be estimated for a particular locale by determining the nitrogen loss from local stabilization pond systems. Volatilization of NH_3 can result in nitrogen removal rates as high as 20 lb/acre.day (22 kg/ha.day) or more. The nitrogen content of water leaving an NH_3 volatilization ATU can be reduced further by passing it through a gas stripping device prior to its entry into the next ATU in which the pH will be reduced.

It appears that the bacterial nitrification/denitrification process has the greatest nitrogen removal potential. Nitrogen losses greater than 50 lb/acre.day (56kg/ha.day) have been monitored in some water hyacinth systems during the summer.

Based on the data reported, the aerobic nitrification steps of the nitrification/denitrification process are limiting, generally, with the anoxic denitrification step occuring at a rate comparable to that of the nitrification steps.

The removal of BOD and the nitrification process are very similar, conceptually. Consequently, the physical designs of these two types ATU are essentially identical with regard to ATU geometry, proportion, and depth,. However, because of the nature of the NOD distributing the influent over an extensive area of the ATU surface is not necessary, in general, unless the BOD load is such that the limit on localized BOD loading is approached.

The information necessary to design a nitrification/denitrification ATU rationally is essentially as outlined for BOD removal since in both cases a quantitative estimate of sources and sinks of oxygen as a function of plant variables and water quality would be the basis of design. Necessary additional information would include:

(1) The leakage of NH_3 from settled matter and plants and:

(2) nitrification rates as a function of plant variables, BOD concentration, water temperature and DO.

3.9.2. Phosphorus Removal

Phosphorus removal rates and effluent concentrations of aquatic systems have not been consistent. Generally, phosphorus removal rates are less than 2 lb/acre.day (2 kg/ha.day) during the summer months and decreases during the winter months when release of phosphorus to the wastewater (instead of removals) are not uncommon.

Nitrogen and phosphorus can be retained in the sediments of an aquatic system to satisfy nutrient and other biochemical demands of the micro-organisms living there. Eventually, the nitrogen would be denitrified to the atmosphere and the phosphorus may become bound chemically to other compounds in the sediments.

3.10 UTILIZATION OF WATERHYACINTH FROM PONDS

The idea to change water hyacinth into a benefit has been worked out for many plants. A compilation of citation on utilization of water hyacinth shows that bio gas, cattle feed and pollution control are most envisaged (joyce, 1990). But in most cases the utilization has remained local and without commercial interest. Some typical utilizations of water hyacinths are described below:

3.10.1 Degradation of water Hyacinth into Biogas

Degradation of bio mass obtained from water hyacinth which has absorbed some metal ions or present naturally appear to depend on the mechanism of "oxygen fixation". The natural biopolymers such as lignin, cellulose, hemicellulose evolved in oxygen atmosphere. Anaerobic bacteria can never have the ability to degrade these highly oxidized polymeric ring compounds. These may be degraded oxidatively, nor reductively.

In presence of metals particularly divalent ions, the mechanism of activation of oxygen is enhanced facilitating the degradation of aromatic and ring compounds of nature to aliphatic acids not only by acidifying bacteria but also by hydrolic degradation of metal-bonded species. The methane from bio mass through anaerobic process. The results of evolution of bio gas in the laboratory from fresh and predigested water hyacinth is shown in Figure 3.4.

Various workers have reported work in the area of production of bio gas from water hyacinth. Some instances are those of Casebow(1967), Wolverton et al. (1975), Wolverton & McDonald, (1990), Pillai et al., (1984), and many others. An experimental plant based on Anaerobic Baffle Reactor type was established in Bangladesh with the help of Technology Development Unit of Warwick University, U K. But the plant was extensively damaged in the flood of 1988 (Haider,1989).

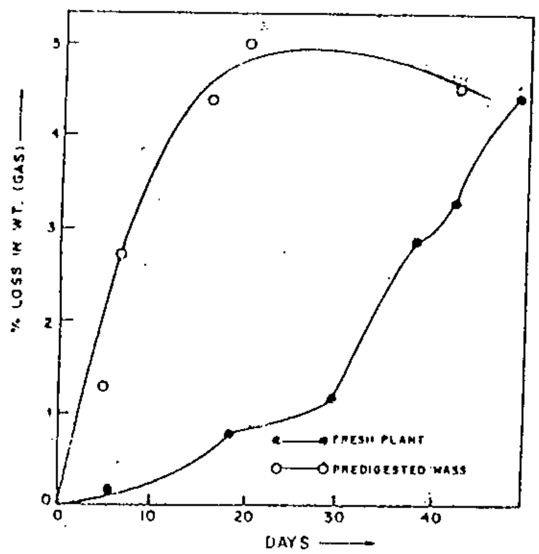

Fig. 3.4 Evaluation of bio gas from fresh and pre-digested water hyacinth(Haider, 1984).

3.10.2 Compost and Fertilizer

An appropriate process has been developed for the production of compost rich in NPK values used as an inexpensive fertilizer which proved very effective with rice plant at an agriculture farm. The compost formed has almost ideal C/N ratio of about 20-25. Details of the production , compost analyses and properties have been described in Figure 3.5

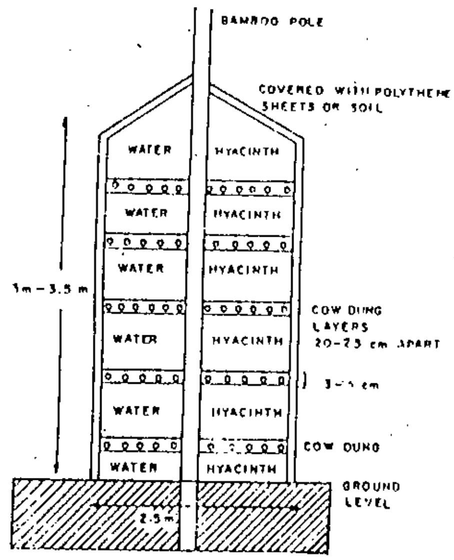

Fig. 3.5 Compost from water hyacinth(Haider, 1984).

3.10.3 Leaf Protein Concentrates

Large scale production of water hyacinth leaf protein concentrate (LPC) has been done with the help of a pilot plant screw press. The amino acids present in the protein hydrolysate mixture of the water hyacinth juice have been estimated. Feeding trials of poultry and cattle feeds extending over a period of 8 weeks have been evaluated with satisfactory results (Kashem et al, 1994). Various other workers have also reported about this aspect of the use of water hyacinth, Boyd (1988), Dutta (1966), Ghosh (1967) , Pirie (1966) and Tailor (1971).

3.10.4 Fabrication of paper and board

Water hyacinth fibers have been fabricated into hard board, ceiling board, reinforced cement board, water-proofing sheets, damp-proof bituminized papers for foundations of buildings, sanitary wares and other items of constructions for use in housing and buildings as well as paper and paper board for office use. Semi-mechanical water hyacinth pulp mixed with jute stick has been fabricated as cheap substitute for use as partition and ceiling boards (Zerroudo 1978, Ghosh 1984).

3.10.5 Hydroponics and agricultural and Horticultural Uses

Floating mats of water hyacinth in the form of double layer hydroponics are in use for growing kitchen vegetables. Cauliflower, gourd, cucumbers, peas, beans etc. could be easily grown for profit or domestic use through scientific management. This method of growing vegetables on water hyacinth floating mats is already practiced by farmers in rural Bangladesh.

Processes using water hyacinth extract (about 90% of the fresh plant) blended with insecticide used as spray for effective means of protection of cereal crops and at the same time providing nutrients from the water hyacinth juice have been developed, Chalkravarty (1984). It has been claimed that protein and amino acids concentrates extracted from leaves contain vitamins and many other pharmaceuticals and drugs could be produced, Sen (19440, Matai (1976), Bhanja & Sircar (1966), Shibata (1965), Vena (1975), Taylor (1971), Bhanja & Sircar (1966).

Dried water hyacinth debries have been successfully used for the cultivation of mushroom, Alicbuson & Ela (1967), Widyanto & Setyawati, (1977). As a rural technology in Bangladesh, the growing of mush rooms for local hotel consumption and for export provides a good opportunity to farmers for economic gains. The roots and rhizomes yield stigmasterol required for some synthetic steroidal drugs. Vomifoliol was extracted from the stem and leaves (Stuart 1976). The roots also contain diosgenin which is the starting material for the synthesis of corgtisone (Vermaa, 1959).Anthocyanin is reported to be isolated from water hyacinth flower (Shibita 1965).

Water hyacinth has long been used for mulching in tea plantations, fruit trees and horticulture (Bailey, 1919) as well as growing maize, peas etc. proved to be successful because the roots are colonized by micorhizal endotrophic fungus which is important for assimilation of phosphates (Venkataramanan 1984), Chakravarty (1984), Dhar & Singh (1965). Lateritic and alkalibne soils containing immobilized phosphate could be treated with water hyacinth for fertility of the soil and availability of phosphorus and nitrogen to the crops (Dhar & Srivastava, 1971: Little, 1968).

The root extract of water hyacinth mixed with water sprayed to jute and rice plant showed significant increase in the height and basal girth and tiller production in jute and rice, Venkataramanan, (1984).

3.11 NUISANCE CONTROL IN POND SYSTEM

One of the major disadvantage of water hyacinth ponds is nuisance problem. If BOD_5 loading in sewage is high then it may cause odors which is objectionable in a residential/commercial area. Treatment of sewage in out side of the town/city may solve this problem. Also by controlling the BOD_5 loading it can be negotiate.

Limits on the BOD loading rate of the surface area in the immediate vicinity of the influent structures to prevent localized, yet significant, production of odors and mosquitoes in this area have not been determined.

Defining the localized BOD5 loading rate [in pounds per acre.day (kilograms per hectare.day)] of the water surface area within 25 ft (7.6 m) of the point of inflow, odors were reported at aquatic systems with localized BOD5 loadings of 66 lb/acre.day and 7,700 lb/acre.day (75 kg/ha.day and 8700 kg/ha.day). Systems with localized BOD5 loadings of 150 lb/acre.day and 1,300 lb/acre.day (170 kg/ha.day and 1,500 kg/ha.day) did not cause odors (Dewante Stowell). No mention of odors is made in numerous reports on aquatic systems with localized BOD5 loadings ranging from 240lb/acre.day-2,500lb/acre.day(270 kg/ha.day-2,800 kg/ha.day). Considering these data, localized BOD5 loading rates to less than 500 lb/acre.day (560 kg/ha.day) may not cause problems.

Fly and mosquito breeding is also a problem in water hyacinth ponds but this can be partially alleviated by introducing larvae eating fish species such as *Gambusia* and *peocelia* into the ponds. It should be recognized that pathogen die off is poor in macrophyte ponds as a result of light shading and the lower dissolved oxygen and pH compared with algal maturation ponds. In their favour, macrophyte ponds can serve a useful purpose in stripping pond effluent nutrients and algae and at the same time produce harvestable bio-mass.

3.12 CONTROL OF WATER HYACINTH

The growth rate o.f water hyacinth is such that it requires frequent harvesting/control. Harvesting plants can have an appreciable affect on the waste water treatment performance, Like reducing BOD and solids load and reducing plant congestion at the water surface, thus, enhancing *Gambusia* (mosquito fish) control of mosquito larvae. Different methods for control of water hyacinth is described as follows:

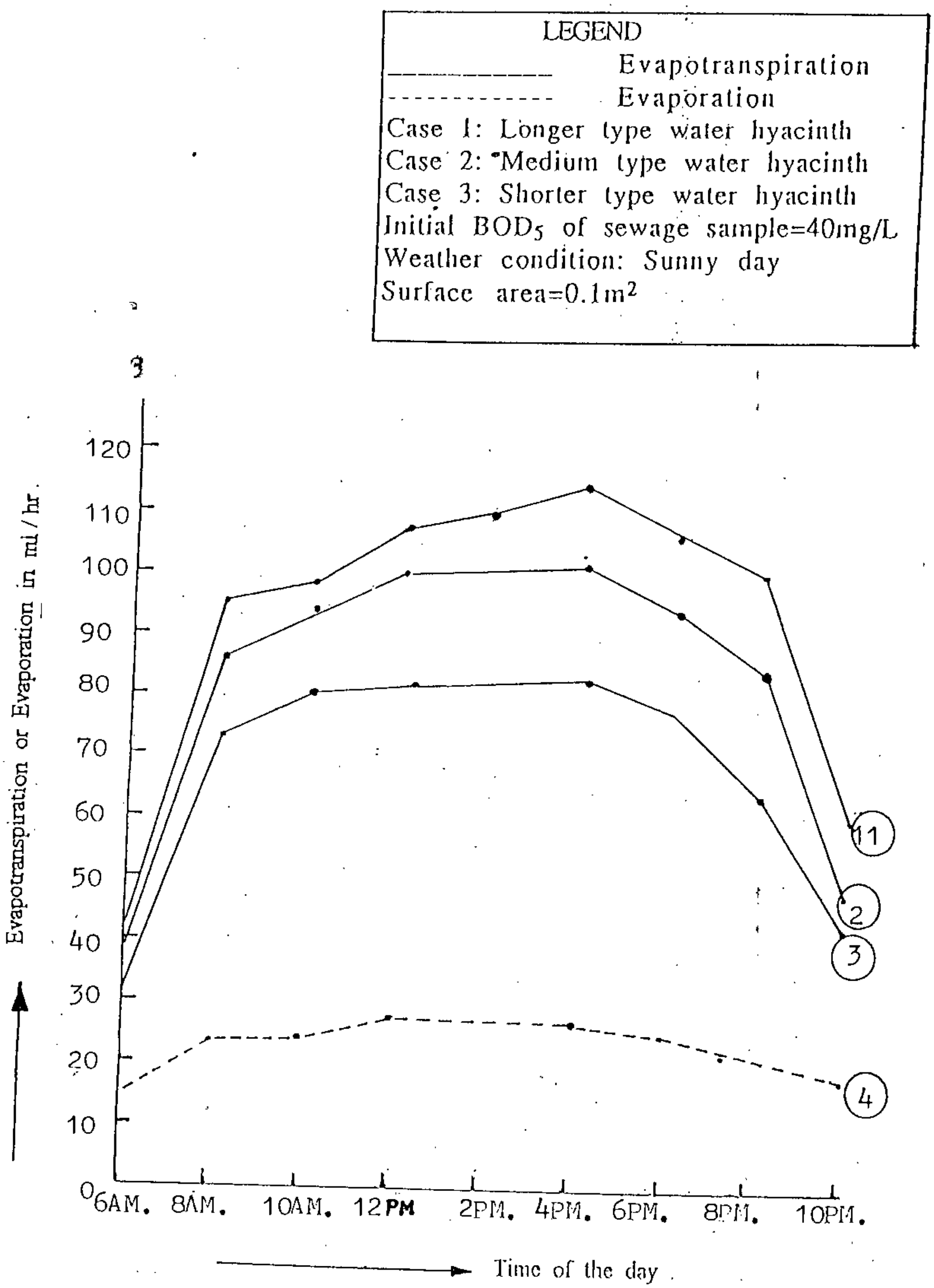

Fig . 4.4 **Evapotranspiration a nd Evaporation from Sewage with different types of water hyacinth .**

evapotranspiration with short root waterhyacinth and 2.7 times higher than evaporation rate at that time.

At 8 AM evapotranspiration rate is 75ml/hr, 87ml/hr and 95ml/hr respectiveluy for the short, medium and longer types of water hyacinth from the basins. The evaporation rate was 23ml/hr from the basin at that time. Thus it is seen that longer type waterhyacinth has evapotranspiration rate 1.3 times higher than short type 1.1 times higher than medium type and 4.13 tmes greater than evaporation at that time. Evapotranspiration rate with short root water hyacinth is 3.26 times higher than evaporation rate.

Again at 12 Noon evapotranspiration rate is 78 ml/hr, 100ml/hr and 108ml/hr respectively for the short, medium and longer type water hyacinth from the basins. The evaporation rate is 27ml/hr from the basin at that time. Thus the longer type waterhyacinth has the evapotranspiration rate of 1.4 times higher than medium type, 1.38 times higher than short type waterhyacinth and 4 times higher than evaporation rate at that time. Evapotranspiration rate with short root water hyacinth is 2.9 times higher than evaporation rate at that time.

Similarly at 4 PM evapotranspiration rate is 94 ml/hr, 101 ml/hr, 119 ml/hr respectively for the short, medium and longer type of water hyacinth from the basins. The evaporation rate is 28 ml/hr from the basin at that time. Thus the longer type of water hyacinth has the evapotranspiration rate of 1.17 times higher than medium type, 1.27 times higher than short type and 4.25 times higher than evaporation at that time. Evaporation rate with short waterhyacinth is 3.35 times higher than evaporation at that time.

4.4 EFFECT OF SEWAGE CONCENTRATION

In this section, evapotranspiration and evaporation rate of water from different sewage sample with a particular type of waterhyacinth were determined.

3.12.1 Harvesting by Manpower

The physical removal by man power is the most direct and simple method. The plants are up taken by manpower and dried on land. It is less expensive and utilizes local manpower which is cheaper and available in the third world country.

The hyacinths dried in simply impervious areas which are sloped so that water released when the plants decompose is drained to a soil adsorption system. Dried plants can be plowed or disked into adjacent farmland. The size of drying and disposal facilities will depend upon the pretreatment provided prior to the hyacinth ponds, the frequency of harvesting, and the local climate.

3.12.2.Mechanical Removal

Depending on the efficiency of the machinery used, water hyacinths are usually cut at the base of the stem leaving the roots and rhizomes untouched. The advantage of mechanical harvesting are that the effects are direct and predictable, when compared to chemical or biological control agents.

But the mechanical removal/control presents technological and operational problems as there has been little effort to develop indignous equipment and most of the imported machines do not suit the field conditions .The machinery is expensive and requires the use of trained personnel. An over view of the machinery used for the control of water hyacinth is made by Robson (1974) and wade(1990), and includes hand held tools, rotary and flail mowers.

Much of the machinery in used today has been developed with specific local needs in mind. The economic effectiveness of these machines are hard to estimate due to the complexity of the operation (cutting, harvesting, transportation and dumping), the period of inactivity and the hidden advantages of nutrient removal. Any approach of mechanical control needs to be evaluated with respect to the management required, paying particular attention to adjacent land use and cost.

3.12.3 Chemical control

Herbicides can offer a cheap, effective and rapid method of water hyacinth control. Herbicide selectivity can be obtained by the use of certain herbicides, by varying their concentration, by the application technique or by the formulation of the herbicide. Herbicides can be applied in management programs only whenever the benefits exceed the hazards by a reasonable margin. Because it can interfere in many way:

- ---- hazards to the user.
- ---- hazards to the receiver of treated waste water.
- ---- directly toxic to plants, mosquito controlling fish.
- ---- directly toxic to lower organisms such as bacteria growth there by reducing the BOD removal.

Also in the case of chemical control of water hyacinth, the plants may lie so close to each other that tall leaves overlap the small leaves and the young daughter plants come under the thick canopy of leaves. Under such conditions all plants do not come in direct contact with a herbicidal spray.

CHAPTER 4

EVAPOTRANSPIRATION AND EVAPORATION RATE FROM SEWAGE WITH AND WITHOUT WATERHYACINTH

4.1. INTRODUCTION

Evapotranspiration and evaporation influences the sewage treatment in a lesser extent but it is important in case of sewage handling. It is based on evaporation, loss of water, to the surrounding air. This evaporation is due to heat provided by solar radiation. But in transpiration, water is lost not from a large water surface but through tiny openings in the leaves,. the stomata. Whether the roots are taming up more water or not, the plant is almost always losing some water through the stomata. This loses of water by plants referred to as'Evapotranspiration' varies with the sewage concentration, temperature, climatic condition, plant types etc. Similarly evaporation rate varies.with different condition To find out the evapotranspiration and evaporation rate of sewage,various experiments have been conducted with the different conditions.

This chapter deals with the experimental determination of evapotranspiration/evaporation rate of water from sewage with and without waterhyacinth in different sewage concentration, with various waterhyacinth type and in different climatical conditions. In this study loss of water was measured in mililiter(ml) and surface area was calculated in square meter (m^2). Since both the evaporation and evapotranspiration occurs uniformly through out the exposed surface area, the evaporation and evapotranspiration rate is expressed in this chapter as $ml/hr/m^2$ of surface area.

4.2 MATERIALS AND METHODS

Water Hyacinth:

The evapotranspiration rate from water hyacinth covered basin has been compared with open water under the same climatological conditions. For this, three types of water hyacinths were chosen. These are

(1) Long stem and having longer root which is comparatively largest size available in our country. Figure .4.1 shows this type of waterhyacinth. The average height of stem is 0.6m and maximum length of root is 0.3m.

(2) Waterhyacinth with Longer root but medium size stem . This type of hyacinth is normally available in ponds. Figure.4.2 shows one of this type. The average height of stem is 0.45m and length of root is 0.2m.

(3) Short steam and smallest size of water hyacinth as shown in Figure.4.3. This type of hyacinth is common in all tropical regions of Bangladesh. The average height of stem is 0.1m and maximum length of root is 0.2m.

Sewage Sample:

In this study three types of sewage sample were collected from different source to conduct the experiments. These are classified as diluted, medium dense and strong sewage which is applicable for this chapter only. Characteristics of these three types are described below.

(1) Sewage taken from main sewer line of Dhaka WASA at 9 AM .. and diluted with water. This is having a low concentration of organic matter and other pollutants. The BOD_5 of this sewage varies from 20 mg/L to 40 mg/L. This is reffered to as diluted

Fig. 4.1 Short stem water hyacinth.

Fig. 4.2 Medium type water hyacinth.

Fig. 4.3. Longer. type water hyacinth.

sewage.

(2) Sewage taken from a drainage line that contains domestic sewage, washings from hotel, Butchery shop, market etc. The sewage of this type is turbid, medium concentrated and gray in colour. The BOB_5 of this type varies from 40 to 80 mg/L. This is named as medium dense sewage.

(3) Sewage having initial BOD_5 value of 80 to 150 mg/L. This type of sewage sample was taken from a dug well of a pit latrine in a residential area. It is classified as strong sewage.

Basins:

The experiment was conducted in different sizes of basin.Among these one type was circular earthen tub. The surface area of this tub was 0.0960 m^2. The capacity of each tub was 16 liter. Another type was rectangular basin having surface area 0.3780 m^2. Depth of each basin was 0.50 m.

4.3 EFFECT OF WATER HYACINTH.

In this section three types of waterhyacinth were placed in three basins having same type of sewage sample. In another basin same sewage sample was kept under direct open exposure in equal volume. Evaporation from this basin and evapotraspiration from othere three basins were observed.

4.3.1 Experimental Set up and Procedure:

Evapostranspiration and evaporation rate with three tyes of waterhyacinth were determined under same climatological conditions. Four earthen tubs (as described in section 4.2) were filled with sewage sample, having an initial BOD_5 of about 40 mg/l. Three types of water hyacinth (as described in section 4.2) were placed in three basins. These three basins with waterhyacinth and one with out water hyacinth were kept exposure to open air. Evaporation and evapotranspiration rate were measured from these basins according to the procedures described below. .

With the beginning of the experiment initial level of sewage sample was marked with coloured pencil. After certain interval of time the reduction of sample was observed. This reduction was measured by adding sample with a graduated cylinder upto the previous mark. The added sewage sample indicates the evapotranspiration or evaporation rate from the basin area. The results are given in tabular form in Appendix A and are shown in Figure4.4.

43.2 Results and Discussion

From Figure 4.4 it is clear that evapotranspiration rate is always higher than evaporation rate. Different types of water hyacinth have different capacity of evapotranspiration. Longer type waterhyacinth higher evapotranspiration capacity than other types of water hyacinth.

During this study period lowest evapotranspiration occured at 6 A M. The evapostranspiration from 10 PM was near about same. The volume reduction in this period (10 PM to 6 AM.)was measured at 6 AM. This reduction is averaged for 8 hours (10 PM to 6 AM). The average value has been considered the evapotranspiration and evaporation rate at 6 AM in this study.

In this experiment evapotranspiration is 41 ml/hr, 37 ml/hr and 32ml/hr respectively for the longer, medium, short root waterhyacinth at 6 AM from the given basin area. Average evaporation rate during this period was 15ml/hr from the basin area. Lowest evapotranspiration is observed with waterhyacinth having short root and stem. This is 2.13 times greater than evaporation at that time. Also evapotranspiration rate with waterhyacinth having longer root and stem is 1.3 times higher than

4..4.1 Experimental set up and procedure:

The experiment was conducted with three types of sewage sample (as described in section 4.2). Smaller type of waterhyacinth were used. These sewage sample were taken in three different basins (as described in section 4.2). waterhyacinth was placed on it. Same sewage sample were taken in another three basins. No water hyacinth was placed on it. All these six basins were kept exposed in open air. Evapotranspiration and evaporation rate from these basins were measured using the technique described in section 4.3.1. Sunny day was available during the experiment. Evapotranspiration and evaporation rate found in this experiment is shown in Figure4.5

4.4.2 Results and Discussion:

In Fig4.5 case 1, 2 & 3 shows the evaporation rate from diluted, medium dense and strong sewage. All the sewage sample were exposed in open air in a single day. Other than sewage characteristics, all the conditions of this experiment was same. But evaporation rate was different for three types of sewage sample. As seen in Fig. 4.5 the evaporation rate from diluted, dense and strong sewage is 24ml/hr, 22ml/hr and 20 ml/hr respectively from the given basin area. It indicates that evaporation is more in weak sewage than in strong sewage. The variation between different evaporation rate is minor as compared to the evapotranspiration rate.

Evapotranspiration rate with these three types of sewage samples are shown in case4, 5 & 6 in the same figure. Evapotranspiration occured by the same type of waterhyacinth from all the basins. Case 4 5 & 6 represents the evapotranspiration rate from sewage sample having innitial BOD_5 of 40mg/l, 100mg/l and 160mg/l respectively. In case 4 evapotranspiration rate is 75ml/h, 80ml/h, 83ml/h, 80ml/h, 96 ml/h and 86ml/h respectively from the basin area at 8 AM, 10 AM, 12 Noon,2 PM and 6 PM. The average evapotranspiration rate for this 24 hour study period is 75ml/h from the given basin

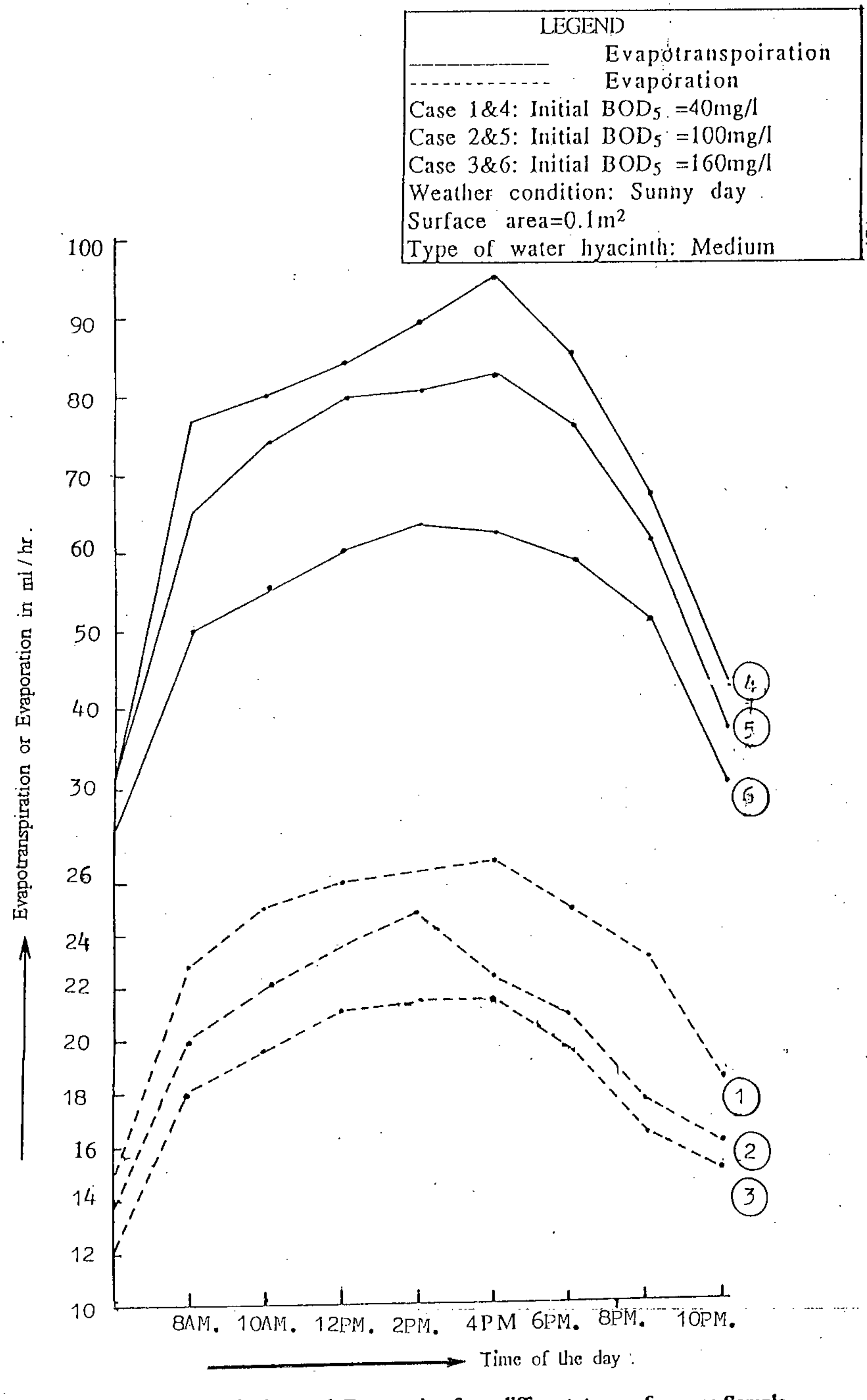

Fig. 4.5 Evapotranspiration and Evaporation from different types of sewage Sample.

area.

Case 5, the evapotranspiration rate is 65 ml/h, 74ml/h,80ml/h, 75ml/h and 82ml/h respectively from the basin area at 8 AM, 10 AM, 12 Noon, 2 PM and 4 PM. The average evapotranspiration rate in this case for the 24 hour period is 60ml/h from the basin area. In csee 6 the evapotranspiration rate is 50 ml/h, 57ml/h, 60ml/h, 54ml/h and 63 ml/h respectively from the basin area at 8 AM, 10 AM, 12 Noon, 2 PM,and 4 PM. The average evapotranspiration rate is 45 ml/h from the basin area.

Case4 shows higher value than case 5, which is again higher than value in case 6. This is clearly shown in Figure 4.5. But sewage used in case 5 is again weaker than 6. This indicates the fact that lower the sewage concentration, higher the evapotranspiration rate. In simple words, the evaporation and evapotranspiration rate with waterhyacinth from sewage decreases with the increase in sewage concentration. In mathematical term this can be expressed as

$$E_p \propto 1/C_S \quad \text{and}$$

$$E_t \propto 1/C_S$$

Where, E_p =Evaporation from sewage.

E_t = Evaptranspiration from sewage by wateerhyacinth.

C_S = Sewage concentration.

Further study/research work is required for finding out the factors determining evapotranspiration and evaporation rate and constants from which an emperical formula may be set up.

4.5 EFFECT OF DEPTH AND SURFACE AREA

In this section evapotranspiration and evaporation rate were determined from different depth of sewage sample. Also evapotranspiration by water hyacinth with the variation of surface area and density of water hyacinth covered the basin were determined.

4.5.1 Experimental set up and Procedure

The effect of basin characteristics i. e depth and surface area were determined by conducting the experiment in two different types of basins. For this two rectangular basins (as described insection 4.2) and one earthen tub were taken for the measurement of evapotranspiration rate. Sewage sample were filled upto the depth of 0.17m and 0.34m respectively in rectangular basin. The earthen tub was filled with same sewage sample. Waterhyacinth were placed on sewage sample in all the three basins. These three basins were kept under direct sunray to measure the evapotranspiration rate. The rate was measured using the technique as described in section 4.3.1.

Same sewage samples were taken in the basins (as described earlier) for determination of evaporation rate in the next day. In the similar way evaporation rate was measured.

According to the above mentioned procedure the experiments were repeated with the variation of surface area and density of water hyacinth. Water hyacinth was placed on rectangular basin which covers about 90% and 50% of the total surface area.

4.5.2 Results and Discussion

In Figure 4.6 case 3 & 4 shows evaporation rate from sewage sample at a depth of 0.34m and 0.17m respectively. Case 1 & 2 gives the evapotranspiration rate from sewage at a depth of 0.17m and 0.34m respcctively. In either case same sewage sample was used and surface area was kept 0.3780 square meter. As seen in case 1 & 2 of Fig. 4.6 evapotranspiration rate varies in smaller quantity with the variation of depth. Case 1 and 2 approximately gives the same result. Because the average evapotranspiration rate is 150 ml/hr and 150.5 ml/hr respectively from the basin in respect to the depth 0.34m and 0.17m. In this study length of water hyacinths root was 0.15m. Normally evapotranspiration rate from sewage by waterhyacinth is

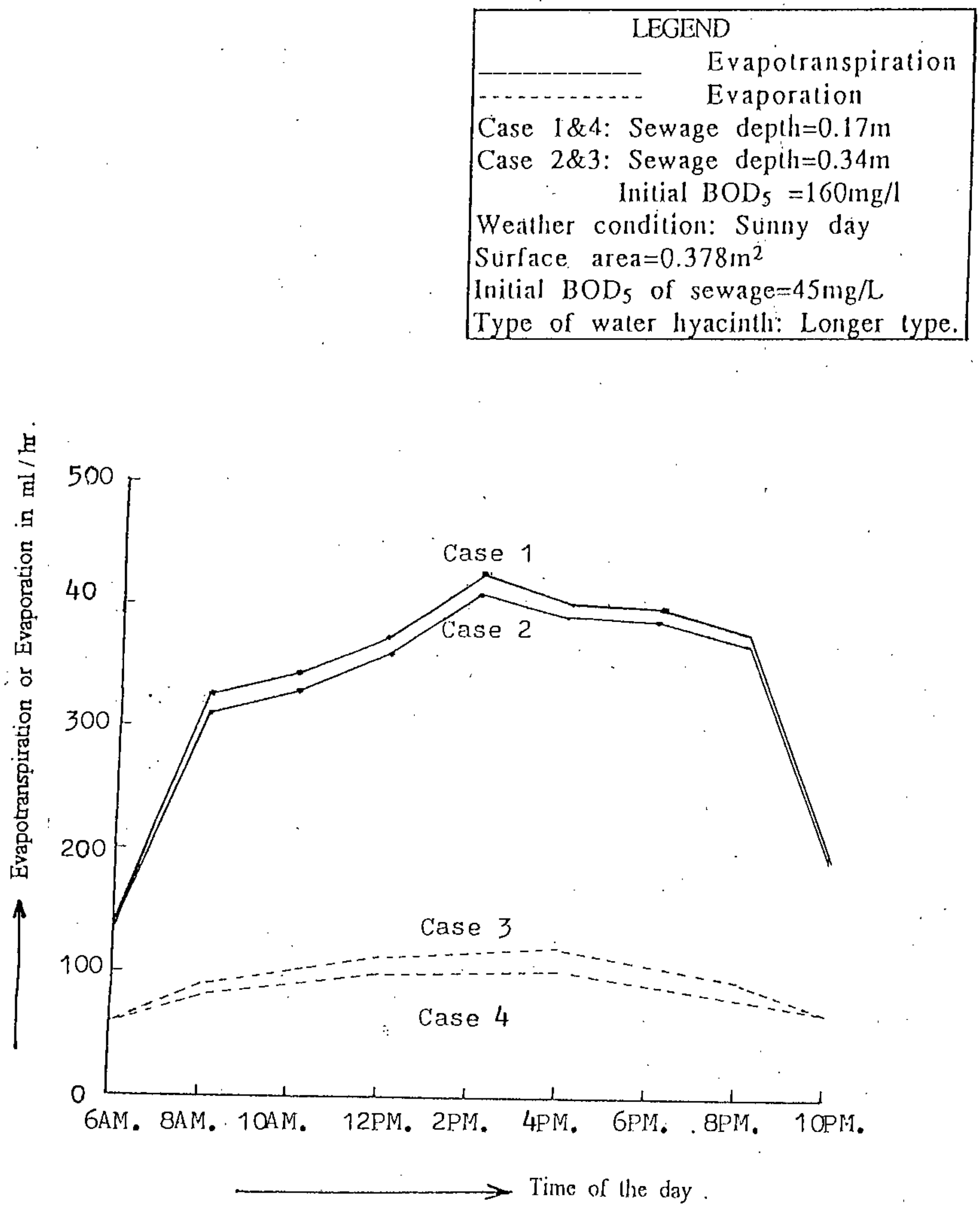

Fig 4.6 Effect of depth on Evaporation and Evapotranspiration rate from sewage .

independent of the depth of sewage, if roots of water hyacinth maintain free floating.

From case 3 & 4 of Fig. 4.6. the average evaporation rate is 50 ml/hr and 46 ml/hr respectively for the depth of 17 cm and 34 cm during the study period. Here evaporation rate from the depth of 17 cm is 1.1 times higher than evaporation rate from 34 cm. It indicates that evaporation rate is more in shallower depth.

Fig.4.7 gives evapotranspiration rate from sewage with water hyacinth from different surface area. In this Figure case 1 gives the evapotranspiration rate by water hyacinth from a surface area of $0.1m^2$. The highest evapotranspiration rate in this case is seen at 4 PM., which is 115 ml/hr from the total surface area. The average evapotranspiration rate for the study period is 78 ml/hr from basin area. In an unit surface area of $0.01m^2$, the highest and average evapotranspiration rate in case 1 is 12 $ml/hr/0.01m^2$ of basin area and 8 $ml/hr/0.01m^2$ of the basin area respectively.

Case 2 of Fig. 4.7 gives the evapotranspiration rate by waterhyacinth from a basin area of $0.3780m^2$. The waterhyacinth covered in this section about 90%of the total surface area. From this curve it is seen that maximum evapotranspiration occurs at 2 PM, which is 420 ml/hr from the basin area. The average evapotranspiration rate during this study period is 81 ml/hr from the basin area. Expressing this in an unit area of $0.01m^2$ and converting results for 100% compacted waterhyacinth density, the highest evapotranspiration rate in this case is 12.34 $ml/hr/0.01m^2$ of basin area and average evapotranspiration rate is 8.2 $ml/hr/0.01m^2$ of the basin area.

Case3 of Fig. 4.7 shows the evapotranspiration rate from a basin area of $0.3780m^2$. But waterhyacinth covered 50% of the total area. Calculating the evapotranspiration rate in the similar way, the highest evapotranspiration rate is $12.17ml/hr/0.01m^2$ of the basin area and average evapotranspiration rate is   ml/h/100 cm2 of the basin area.

Hence evapotranspiration rate is uniform through out the surface

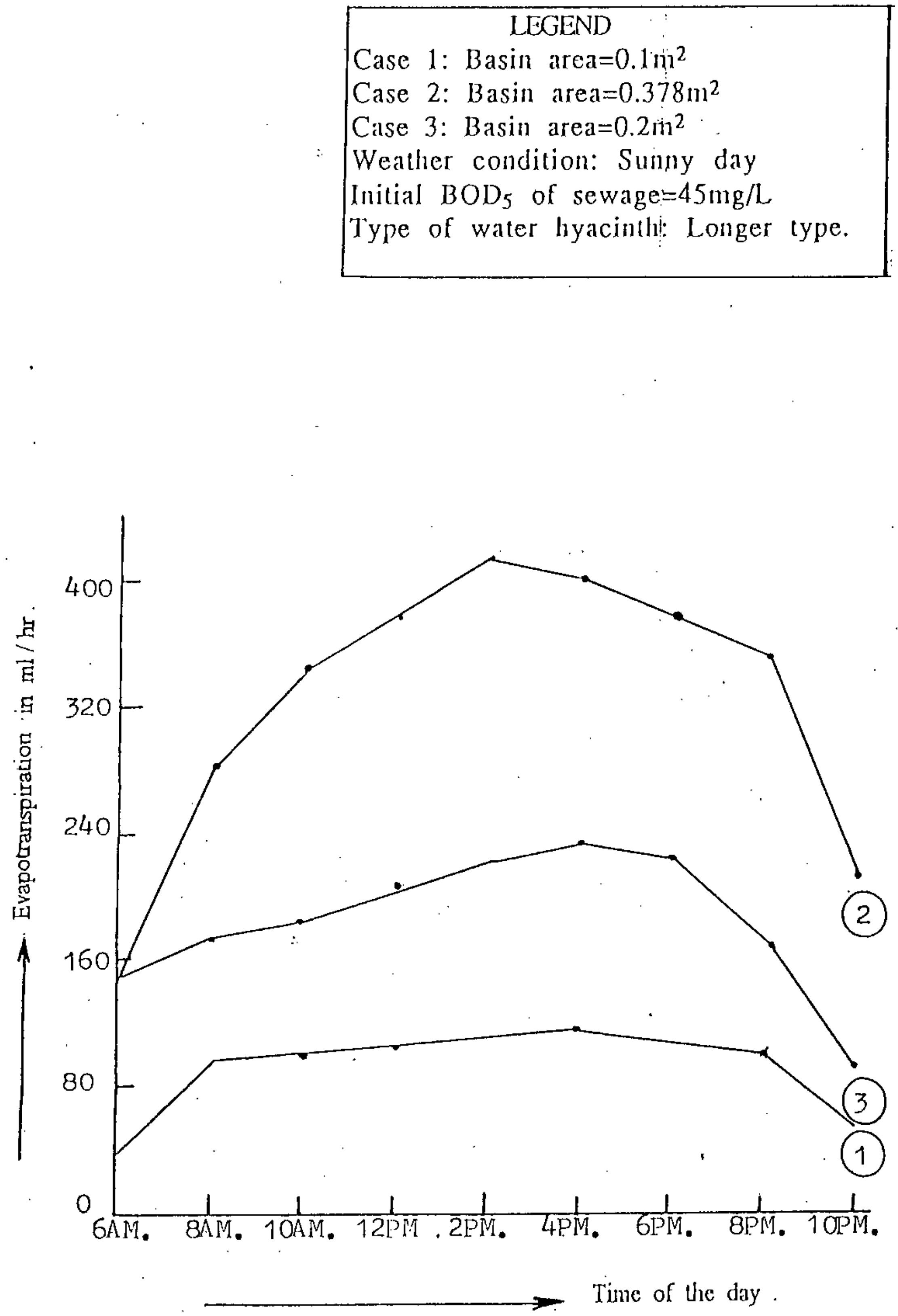

Fig . 4.7 Effect of surface area on Evapotranspiration rate from sewage sample with water hyacinth .

area and it varies with the density of water hyacinth. Moreover, using water hyacinth, sewage volume reduces considerably. This is advantageous in case of sewage handling.

4.6 SUMMARY OF FINDINGS:

01. Longer type waterhyacinth has the highest evapotranspiration capacity. This is about 1.15 times higher than medium type, 1.3 times higher than short type waterhyacinth.

02. Evapotranspiration rate is higher than evaporation rate at any time. For longer type waterhyacinth evapotranspiration rate is 2.5 to 4.5 times than evaporation rate. Medium type waterhyacinth has evapotranspiration capacity of 2.25 to 4 times higher than evaporation. For short type this is 2 to 3.5 times higher.

03. Highest evapotranspiration occured within the period 2 to 4 PM.

04. In average evapotranspiration at day times is three times than evapotranspiration at night.

05. Both the evapotranspiration and evaporation rate is observed inversely proportional to the sewage concentration.

06. Depth and surface area has little effect on evapotranspiration and evaporation.

CHAPTER 5

POLLUTANTS REMOVAL IN WATER HYACINTH POND SYSTEM

5.1 INTRODUCTION

In batch culture the organic loading (as represented by BOD or COD loading in the system) is removed mainly by sedimentation, for the particles which is heaviER and larger from water: the settling basin provides a quiescent environment that enables particles of specific gravity greater than water to settle to the bottom. The colloidal/soluble bod is removed as a result of metabolic activity by micro-organisms which is on the surface of the roots in water hyacinth.

This metabolic activity is done by some bacteria which can be considered as tiny automatic chemical reactors. Bacteria converts the elements from organic forms to their most highly oxidized organic forms. It has been found that BOD removal often approximates first order kinetics; that is to say, the rate of BOD removal (= rate of oxidation of organic matter) at any time is proportional of the amount of BOD (= organic matter) present in the system at that time.

Removal of organic matter in flowing condition varies from batch culture, since the removal rate/efficiencies depends on the sedimentation process, sewage characteristics, temperature, growth pattern of water Hyacinth and aerobic/anaerobic condition. In flowing condition the settling velocity of particles is more as it strikes the roots of the water hyacinth, particles settles due to gravity as well as due to settling velocity.

Experiment conducted for the removal of organic matter in flowing condition actually represents the sewage treatment with water hyacinth in a series of ponds. From the scientific literature available it is seen that ponds in series produces better effluent quality than a single one. Thus it is more practical to find out the removal efficiencies in flowing conditions with series of ponds.

The presence of nitrogen and phosphorous compounds in an effluent causes pollution in the receiving waterway. Phosphates and nitrates stimulate eutrophication, nitrates and nitrites may give rise to a health hazard, ammonia has a high oxygen demand and can also be toxic to aquatic life. Phosphates enter into sewage from biological wastes and residues. Suspended solids (SS) present in sewage also considered as pollutants.

Prior to find out the effective pollutant removal rate from sewage with water hyacinth, selection of water hyacinth type based on growth rate and survival test is required.

This chapter deals with the experimental determination of Pollutants removal from sewage with water hyacinth. Survival and growth rate of water hyacinth in Sewage sample was observed at the beginning of the investigation. Sewage was treated with and with out water hyacinth in batch culture, to find out the organic matter removal rate. Moreover sewage simple was run in low velocity with longer root water hyacinth on sewage surface in one cycle. In another cycle only sewage was allowed to flow having no water hyacinth on sewage. The pollutants removal from two cycles were determined.

5.2 GROWTH RATE AND SURVIVAL TEST OF WATER HYACINTH

In this section water hyacinth type is selected for conducting further experiment.

5.2.1 Introduction

Understanding the biological response of water hyacinth is of prime requirement for use it in sewage treatment. This situation is partly due to differences in the environments encountered in natural streams, and in the enriched media provided by water hyacinth. Thus it is necessary to identify the favourable conditions for use of water hyacinth in sewage, so that installations designed for the removal of nutrients or toxic materials should be operated at the practical growth rate. For convenient use of water hyacinth knowledge of plant growth is important. In this section biological characteristics and response of water hyacinth in different sewage sample was observed.

5.2.1 Materials and Method

For determination of growth rate and survival test of water hyacinth the experiment was conducted in rectangular tanks of size of 63 cm x 58 cm x 53 cm. Two types of water hyacinth were collected from marshy land near Tejgaon industrial area. These two types are:

(1) Short steam and smaller size water hyacinth
(2) Long stem and larger size water hyacinth

Sewage Sample

Domestic sewage with different concentration were used.

5.2.2 Experimental set up and Procedure

In order to obtain results at various conditions, samples were varied ranging from tap water to concentrated sewage. Tap water was taken in the rectangular tank. The water hyacinth was placed on sample which covers about 50% of the surface area of the

Table 5.1. Survival test of water hyacinth in sewage.

Duration days	Type of Sewage	Physical observation Longer Type	Short type	Remarks
	Medium	No change	No change	
1	weak	No change	No change	
	very weak	No change	No change	
	Medium	No shines on leaf	No shines on leaf	
2	weak	No change	No shines on leaf	
	Very weak	No change	No change	
	Medium	Start wilt	Wilted	
3	Weak	No change	Wilted	
	very weak	No change	No change	
	Medium	Wilted	Leaves drying	
4	Weak	Volume increasing	Leaves drying	
	Very weak	Volume increasing	Volume increasing	
	Medium	Leaves drying	Stems fall down	
5	Weak	No change	Tends to fall	
	Very weak	Volume increasing	Volume increasing	
	Medium	Steams fall down	Complete death	
6	Weak	New branch	stems fall down	
	Very weak	New branches	New branches	

* Values of BOD_5(mg/L) are classified as Medium=110-220, Weak=50-110, Very weak=10-50.

tank. The increase in volume of water hyacinth was observed. The experiment was repeated with different sewage sample.

5.3.3 Results and Discussion

The growth rate of both the types of water hyacinth were found near about same in tap water. It becomes double after 8 days which was measured by occupation of the total surface area. In sewage sample the growth rate of smaller size was found slower than larger size. After 6 days. longer water hyacinth covers total surface i.e it changed into double. But smaller type water hyacinth occupied about 80% of the surface area.

Water hyacinth can survive upto a certain limit of organic matter and other metals. From Table 5.1 it is seen that smaller size water hyacinth can survive upto a BOD5 of 60 mg/l. But longer water hyacinth can survive easily upto a BOD5 of 100 mg/l.

During this study it has been found that water hyacinth is best suitable for low and very low concentrated sewage. In raw sewage having initial BOD5 of about 120 mg/l, water hyacinth could not survive. It starts becoming wilt from the 2nd days of the treatment and completely died after 5th day.

5.3 REMOVAL OF ORGANIC LOADING IN BATCH CULTURE WITH AND WITHOUT WATER HYACINTH

This section deals with the experimental determination of organic matter removal from sewage with water hyacinth in batch culture. Sewage were treated with water hyacinth in basins. BOD and COD tests were done with the sewage sample taken from the basins. It gives the amount of organic matter present in sewage. From BOD and COD test results organic matte removal rate was calculated.

5.3.1 Materials and Method

Sewage Sample:

For the first set of test, sewage sample was collected from a dug well which is adjacent to a latrine. The location of this well is in south Badda, Gulshan, Dhaka. From this well raw sewage was collected by sweepers. This was purely domestic in nature and contains mostly human faeces and urine. Some other parameters are given below.

pH	: 7.6
Turbidity	: 450 NTU
Nitrate - N	: 19.5 mg/L
Temperature	: 29°C
DO	: 0.5 mg/L
Colour	: Dark grey

High organic matter was found in this type of sample (COD value varies from 200-400 mg/L). Since from the survival test it is seen that water hyacinth can not survive in this strong sewage, the raw sewage was diluted. Sample of various strength was prepared from this by mixing fresh tube well water with this in different percentages. Very low concentrated sewage sample was collected from Dhaka WASA sewer line for this experiment also.

Basin

Initially earthen tub was used as a basin. The depth of which was 0.30 m and surface area = 0.0960 m2. Also rectangular basins of size 0.60 m x 1.20 m and 0.60 m x 0.63 m were used for this experiment.

5.3.2 Experimental set up and procedure:

Two sets of circular earthen basin (as described in section 4.2) were taken for this experiment. Each set contains three circular earthen tubs as described in section 4.3. Both the sets were filled with the various sewage samples as described in section 5.3.1. From each basin sewage sample (about 250 ml) was taken in air tight bottle and transported to the environmental engineering laboratory for respective BOD and COD test. BOD and COD value found from these samples give the amount of organic matter present before treatment. Water hyacinths were placed in one set of basin. Both the sets were kept expose in open air. After each 24 hour interval sample from each basin was taken in air tight bottle and respective BOD and COD tests were done using the technique as described in section 5.4. The results found from these samples gives the amount of organic matter present after treatment. Thus the removal is calculated. Results are given in tabular form in Appendix B and are shown in Figure 5.1, 5.2 and 5.3.

To get a clear idea about the removal rate by sedimentation during this period COD tests were done after 1 hour interval. The hourly COD variation in batch culture for the first 24 hours is shown in Figure 5.5.

5.3.3 Results and Discussion

From Figure 5.1, 5.2 & 5.3 it is well understood that removal of organic matter with water hyacinth is higher than removal from without water hyacinth system. This is because longer roots of water hyacinth provide adequate surface area for the adsorption of organic matter present in sewage. Huge amounts of SS and organic material get attached with the roots of water hyacinth. This process is absent in case of without water hyacinth system. As a result removal of organic matter is more with water hyacinth in batch culture.

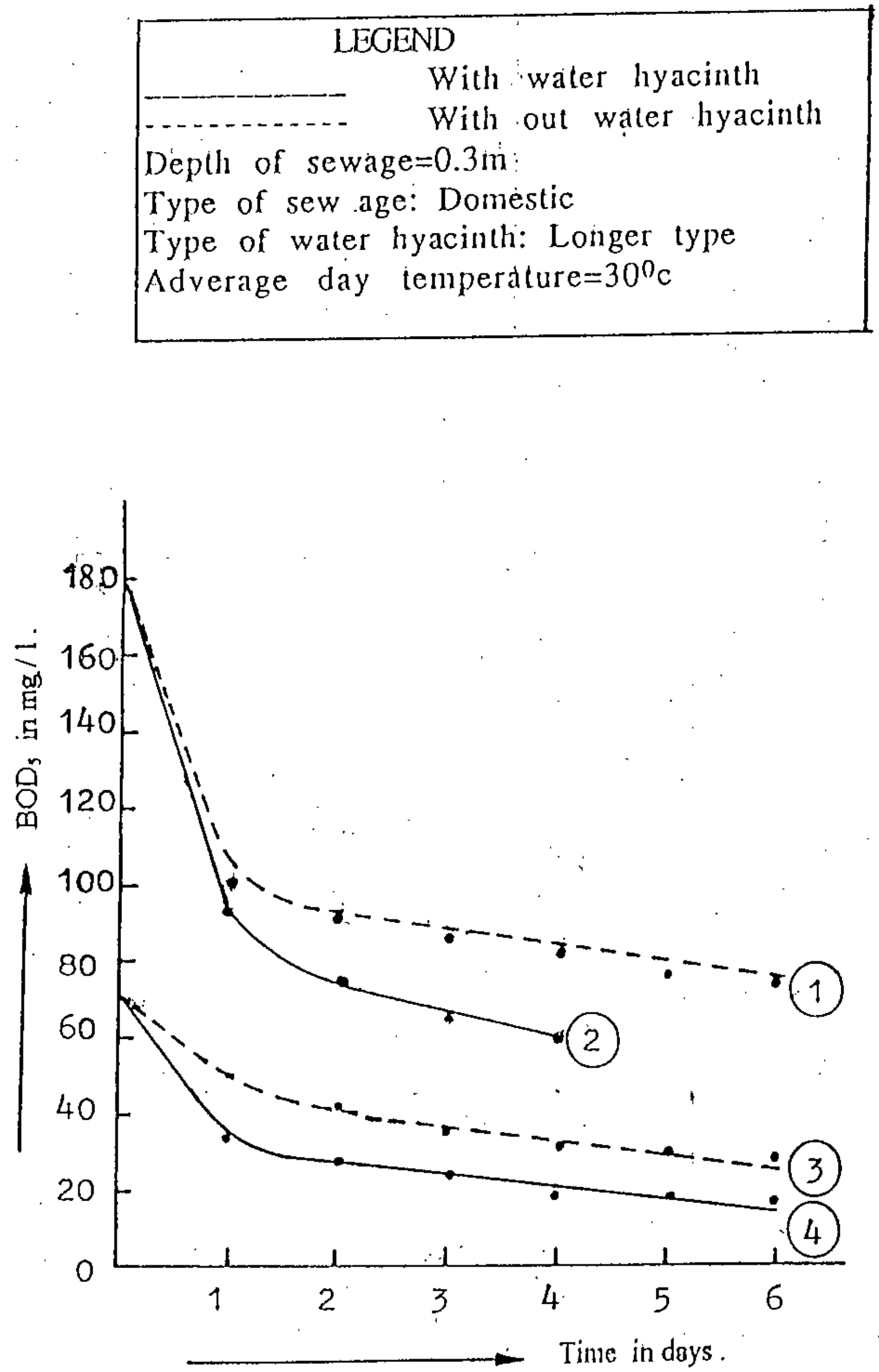

Fig. 5.1 **BOD removal from different concentration of sewage in batch culture.**

The removal rate varies with the sewage concentration Fig. 5.1 shows the BOD removal from two types of sewage sample. In this Figure case 1 & 2 gives BOD values after each 24 hour interval from a sewage sample having initial BOD_5 of 180 mg/l, which was treated in batch culture with and without water hyacinth.

For the first 24 hours the removal is maximum. In this Figure BOD removal rate is 50% and 44% respectively with water hyacinth and without water hyacinth system. after 24 hours removal rate decreases. After 5 day BOD removal of 64% has been found with water hyacinth and 58% without water hyacinth.

In the same Figure case 3 & 4 gives BOD removal in another day from sewage sample having initial BOD_5 of 70 mg/l. In this case BOD removal is 45% and 35% respectively from water hyacinth and without water hyacinth system during 24 hours. After 24 hours removal rate is observed lower. Total BOD removal in 6 days is 76% and 63% respectively for the weaterhyacinth and without water hyacinth system. In this study, comparison between case 1 & 3 for the first 24 hours gives a clear picture of sedimentation removal. For the first 24 hours, organic matter removal rate in case 1 is greater than removal rate in case 3. It indicates quick settlement of heavier particle from higher concentration of sewage. In the similar manner all other cases is analyzed and tabulated in Table 5.1a and 5.1b.

From different cases and Table 5.1a and 5.1b it is seen that organic matters remove in two phases: Maximum organic matter removes within first 24 hours. During this period BOD removal rate is found more in higher concentrated sewage. as seen in Fig. 5.4 as the sewage concentration increases the removal rate also increases, especially, in the water hyacinth system. This is due to the sedimentation of sewage which occurs during this period. This sedimentation is accomplished due to the gravity of heavier particles. Since weak sewage contains less suspended

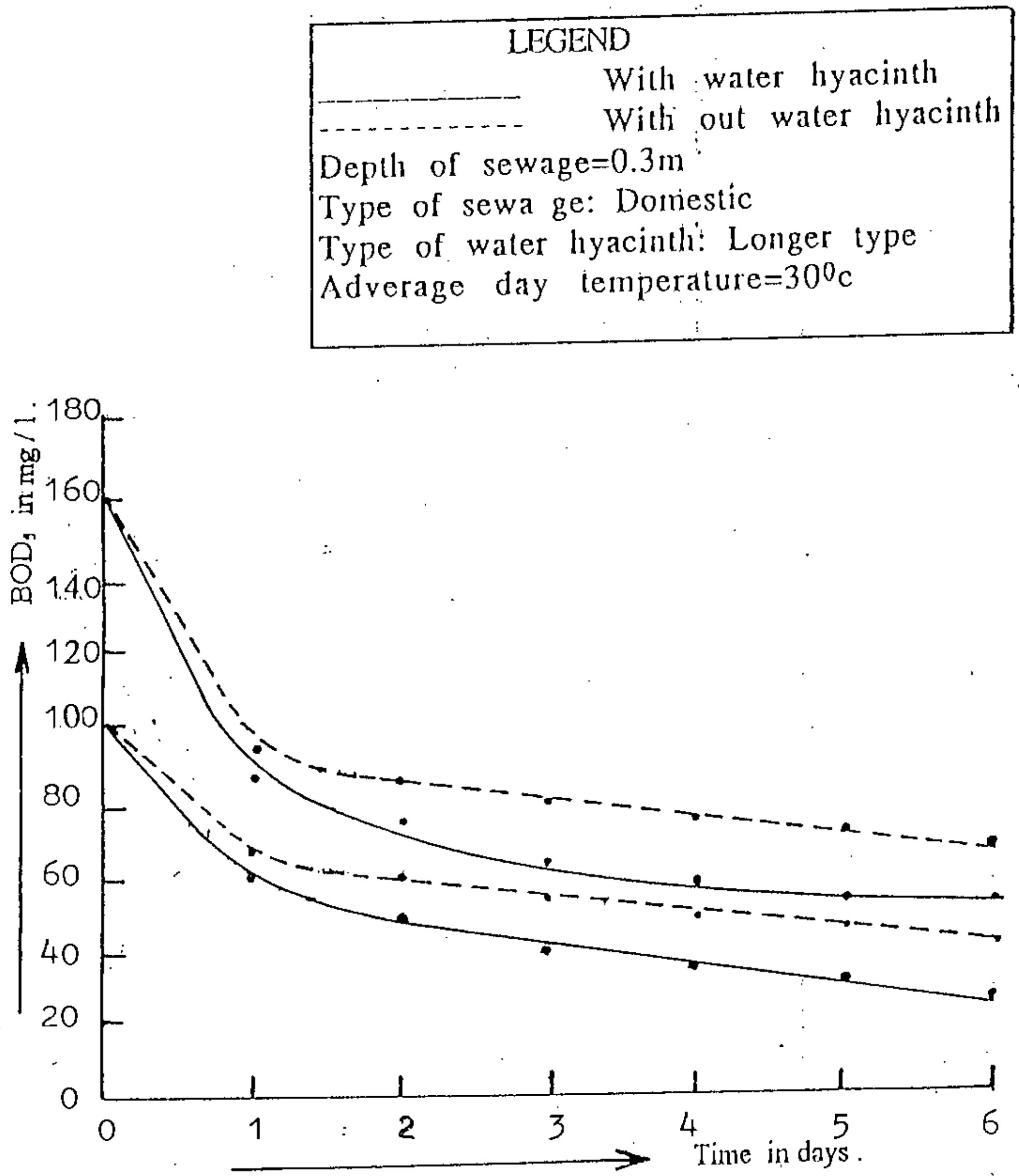

Fig. 5.2 **BOD removal from different concentration of sewage in batch culture.**

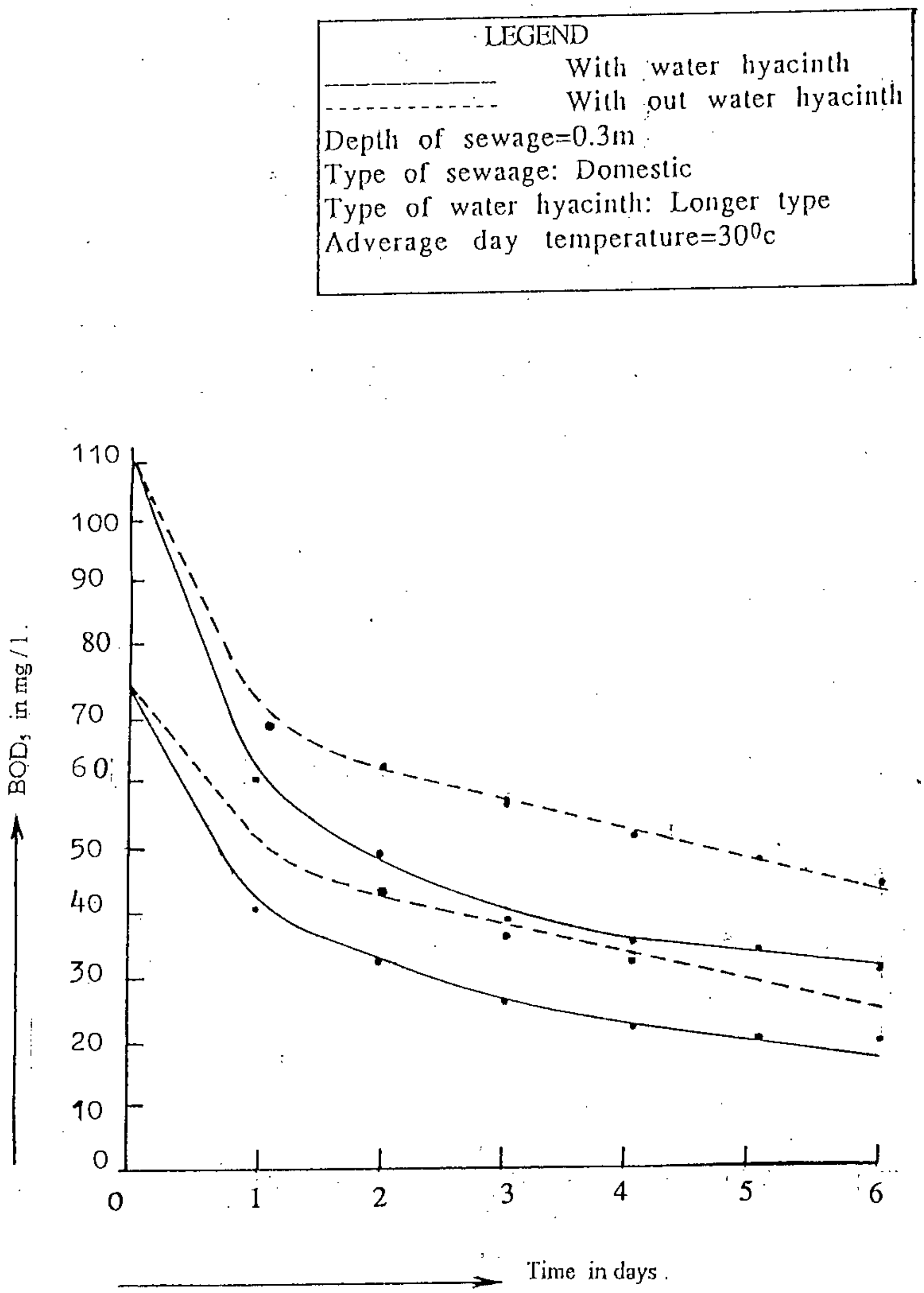

Fig . 5.3 BOD removal from different concentration of sewage in batch culture .

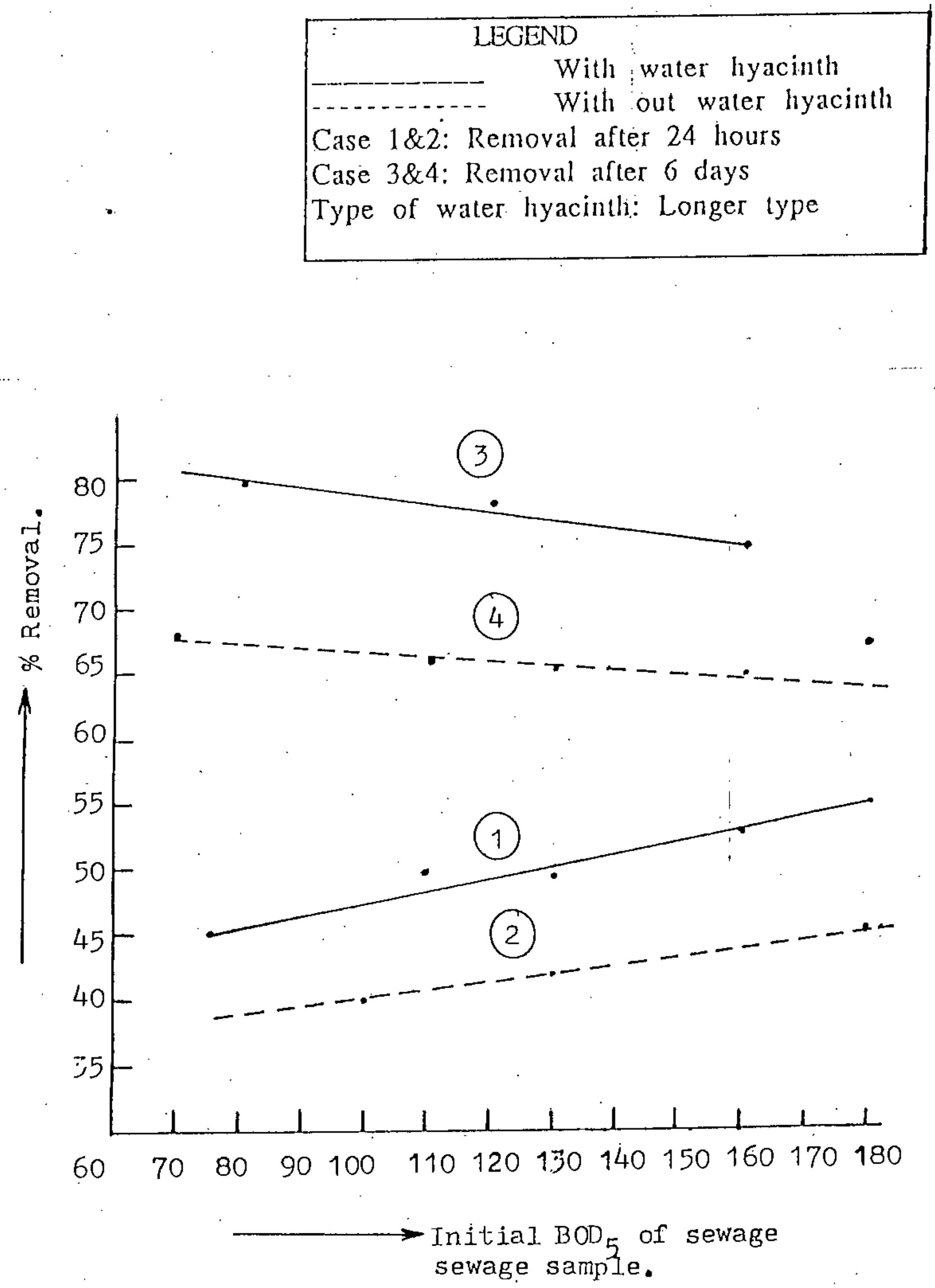

Fig . 5.4 **Variation of BOD removal rate with sewage concentration in batch culture .**

Table 5.1.a BOD Removal Rate from Different Sewage Concentration.

Sl. No.	Initial BOD (mg/l)	% Removal			
		After 1 day		After 6 day	
		With W.H	Without W.H	With W.H	Without W.H
1	180	50	44.5	64*	58
2	160	47	43.5	69*	59.5
3	110	45.5	36.5	73	61
4	100	42	35	74	61
5	75	40	33.5	75	62.2
6	70	40	35	76	63

* BOD Value found in 5th day.

W.H = Water hyacinth.

Table 5.1.b COD Removal Rate from Diffrent Sewage Concentration

Sl. No.	COD	% Removal			
		After 1 day		After 6 day	
		With W.H	Without W.H	With W.H	Without W.H
1	390	49	43.5	65*	59
2	320	47	42	68*	59.5
3	195	43.5	38.5	73	61.5
4	170	41	38	73.5	61.75
5	160	40	37.5	75	62.5
6	145	38	35	76	63.5

* COD Value found in 5th day.

W.H = Water hyacinth.

solids and heavier particles, organic matter removal is also low during the first 24 hours.

But the reverse situation is seen in case of sewage treatment after 24 hours. Fig. 5.2 and 5.3 shows organic matter removal from different concentrated sewage sample after 6 day treatment. In this experiment highest removal with water hyacinth occurred 76% from sewage having initial BOD_5 of 70 mg/l and lowest removal of 64% is found from the sewage sample having initial BOD_5 of 180 mg/l.

High concentrated sewage contains tremendous amount of SS, heavier particles and dissolved organic material. Hence due to the gravity action maximum organic particle settle within first 24 hours. After 24 hours organic matter removes mainly due to the microbial activity and adsorption of colloidal materials with the roots of waterhyachinth. The rate of removal is decreasing with time. On the other hand weak sewage contains lesser amount of SS and heavier particles. For this reason removal by sedimentation within first 24 hours is less. But removal process is similar to the previous process after 24 hours. Since the sewage contains smaller quantity of organic matter, the removal rate is more after 24 hours. It is evident from the Fig. 5.4 and as well as from Table 5.1.a and 5.1.b that removal of organic matter with waterhyachinth increases with the decrease in sewage concentration. Moreover, weak sewage is more aerobic than strong sewage conditions and that may influence in removing organic loading faster in weak sewage treatment and need detail study in this area.

Removal of organic matter with water hyacinth is higher than without water hyacinth system in both cases. In this study average BOD removal during first 24 hour period has been found 44% with water hyacinth, and with out water hyacinth it is 38%. After 6 day treatment BOD removal with water hyacinth is 71%. Without water hyacinth the removal is 61%. Thus it is seen that

LEGEND

——————— With water hyacinth

- - - - - - - - With out water hyacinth

Depth of sewage=0.5m

Type of sewage: Low concentrated

Type of water hyacinth: Longer type

Adverage day temperature=32.5^{0}c

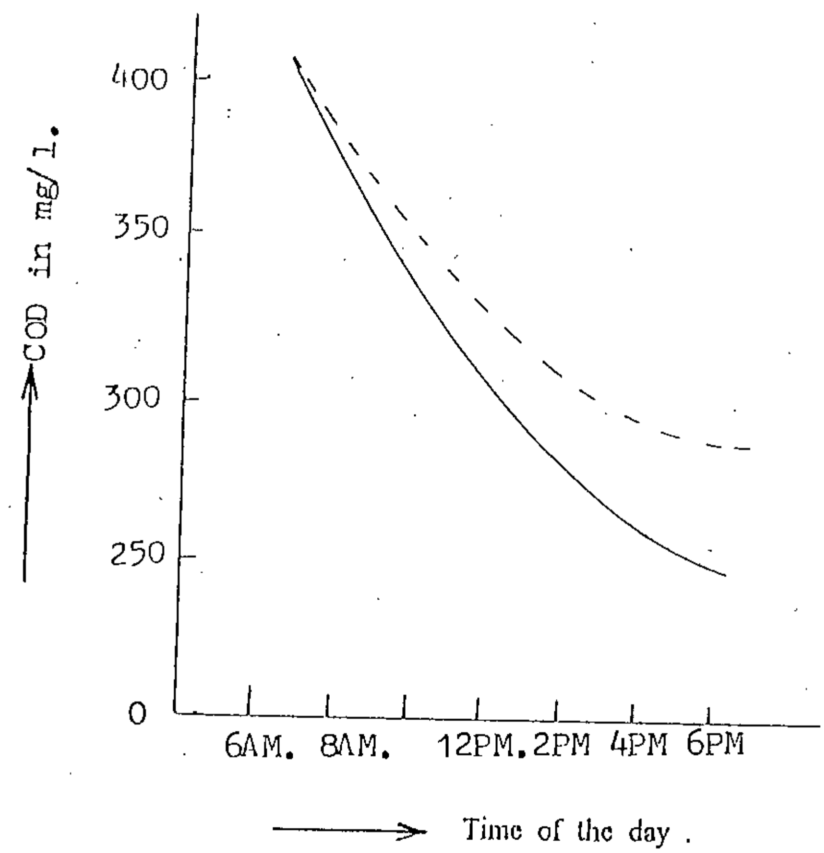

Fig . 5.5 Hourly COD removal in in batch culture .

organic matter removal from sewage in batch culture is higher by 6 to 10% due to the use of water hyacinth in the pond system.

As seen in Fig. 5.5 COD removal is rapid for the first 5 hours. After this time removal rate becomes lower. In this

Figure 29% removal is seen after 5 hour treatment with water hyacinth and 24% removal corresponds to without water hyacinth system. During 12 hour observation COD removal rate is found 40% with the water hyacinth and 32% with out water hyacinth.

5.4 REMOVAL OF ORGANIC LOADING IN FLOWING CONDITION WITH AND WITH OUT WATER HYACINTH

In order to design the pond system to treat sewage with water hyacinth, knowledge on determination of organic loading removal rate in flowing condition is the key element which need to be determined. In this stage of the study experiment was designed in order to evaluate:

i) The BOD and COD removal in flowing condition from three rectangular basins, connected in series.

ii) The difference of removal rate between sewage treatment (pond system) with water hyacinth and without water hyacinth.

5.4.1 Materials and method:

Sewage Sample:

Sewage samples for conducting experiment in flowing condition were collected by sweeper. These sewage were collected from pumping station of the main sewer line of Dhaka WASA, which is located near Dhaka medical college Hospital.

Sewage were collected into 12 plastic containers containing about 26 litre sample each. Transported to the BUET campus, where arrangement has been made for conducting experiment to determine the BOD removal performance of sewage using watrhyacinth in flowing condition. Four circular drum of each 160 litre capacity were filled with this sewage and kept ready for the study.

Sewage were collected from the main sewer line of Dhaka WASA at the peak hour i.e from 7.30 AM to 9.30 AM. Before starting of the experiment sewage samples were taken into a BOD bottle for determination of some physical and chemical parameters of raw sewage.

Sewage Quality:

Some general physical and chemical properties of sewage were assessed in the laboratory.

The datas are given below:

pH	= 7.5
Turbidity	= 12 NTU
COD	= 130 mg/l
Nitrate-N	= 7 mg/l
Temperature	= 29°C
DO	= 1.5 mg/l
Colour	= Light gray.

Flow Arrangement:

Three rectangular basin were connected in series. Average depth of each basin is 0.50 m. The surface area of one basin is 120 m x 0.60 m and the another two having 0.63 m x 0.60 m. The glass fittings in longer side of the basins provide facilities for observation of settling/sedimentation process, accumulation of

Fig. 5.6 Sewage treatment in pond system (rectangular basins connected in series) at BUET campus.

sludges etc. The average capacity of these basins are 360 and 180 liters respectively.

The basins were connected with two circular drums at the inlet and with another two circular drums at the outlet end. The capacity of each drum is 160 litre. Both the drums and basins were connected in series.

Water hyacinths covered about 50% of the total surface area of the basin, which provides the growth and expansion for the future. Continuous flow of sewage were maintain by pumping the sewage sample from the outlet end to the inlet end. Figure 5.6 shows a general view of the whole arrangement for conducting the experiment.

5.4.2 Effect of sewage concentration on removal rate:

In this section experiments were conducted with medium, dense and weak sewage in flowing condition. Two cycles of sample flow were carried out with each type of sewage. Sewage was treated with water hyacinth in one cycle. Without water hyacinth in another cycle.

5.4.2.1 Experimental set up and procedure:

To start with the experiment all the three basins were filled with raw sewage. Water hyacinths were placed on the surface of the sewage. A low velocity flow condition was maintained by controlling a gate valve at the inlet end of basin. At this stage a flow rate of 50 litre/hour was recorded. Treated sewage were collected into two drums at the outlet end. These sewage were feed into the inlet drum for circulation. Sludge accumulated at the bottom of the basins were drained out through drain pipe at the bottom after a certain interval of time.

Sewage samples from the final effluent tank were collected in

BOD bottle and transported to the environmental engineering laboratory for successive BOD and COD test, as a measure of organic matter present in the sewage sample. The sample were diluted and aerated depending on the requirements.

For BOD (Bio chemical oxygen demand) test, standardized laboratory procedure was followed. For the same sample the BOD values were determined for four days, these were preferably 1 day, 3 day, 5 day and 7 day respectively. Among these, 5 day BOD value is considered for the analysis of experimental results which was find out after interpolation of BOD values or from setting out of curves.

5.4.2.2 Results and Discussion:

The BOD and COD test results found in various stages are given in tabular form in Appendix B and are shown in Figure 5.7. It is evident from Fig. 5.7 that organic matter removal characteristics is similar to those found in batch culture, i.e maximum removal occurs within 24 hours. After this period the removal rate from sewage is slower rate. Within this period BOD removal is more in flowing condition with waterhyachinth than in batch culture. But during this 24 hours, organic matter removal in flowing condition without water hyacinth is less than those found in batch culture.

From Figure 5.7,it is seen that BOD removal after 6 day is 73.5% and 57% respectively with water hyacinth and without water hyacinth in comparison to 65% and 59% removal in batch culture. Whereas, Reddy and Debusk (1987) found in a similar study in florida that the removal of BOd with water hyacinth ranges from 60% to 70% in different conditions. The result obtained in Author's study is in higher side than the study performed by Reddy and Debusk (1987).

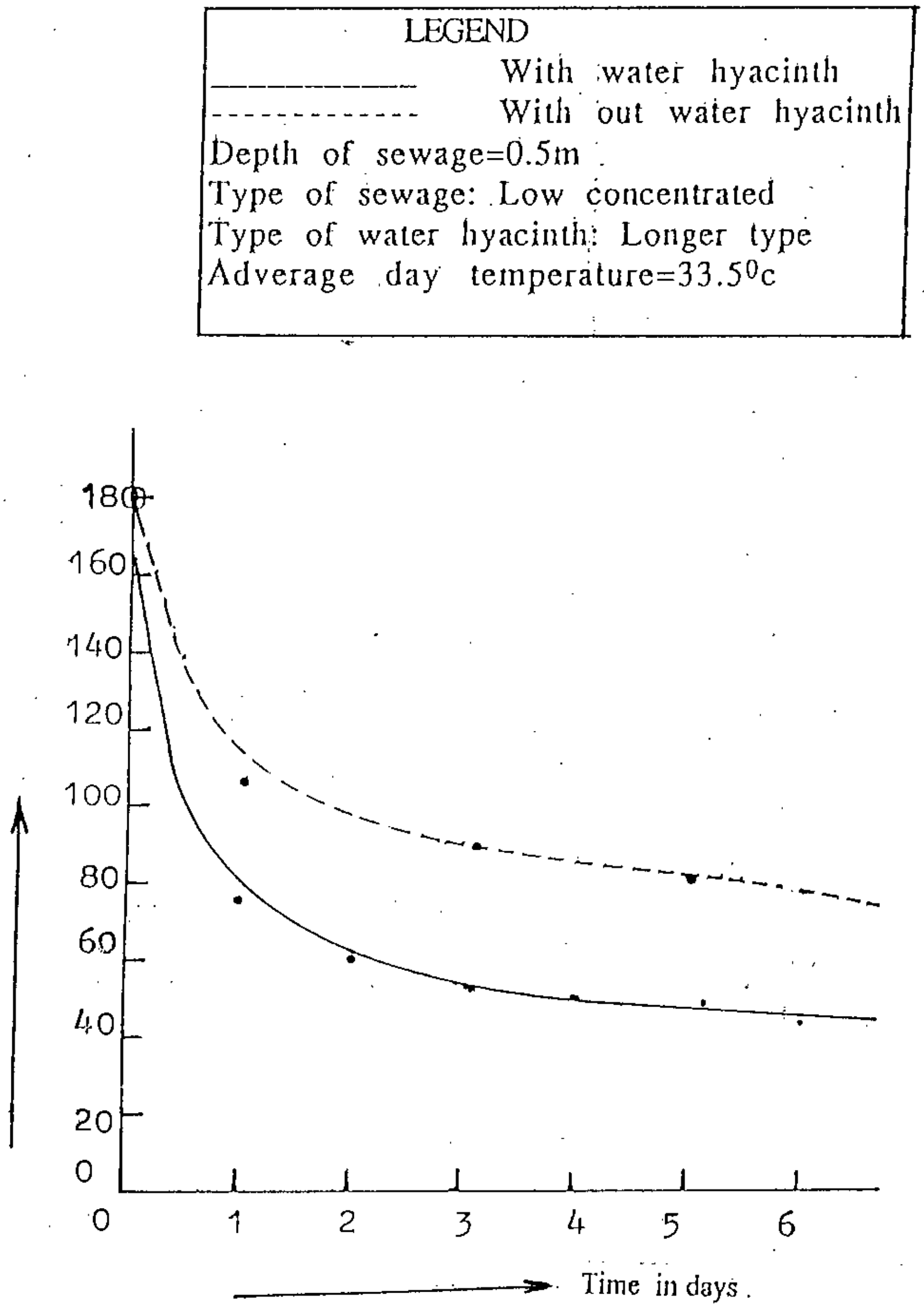

Fig . 5.7 BOD removal in flowing condition.

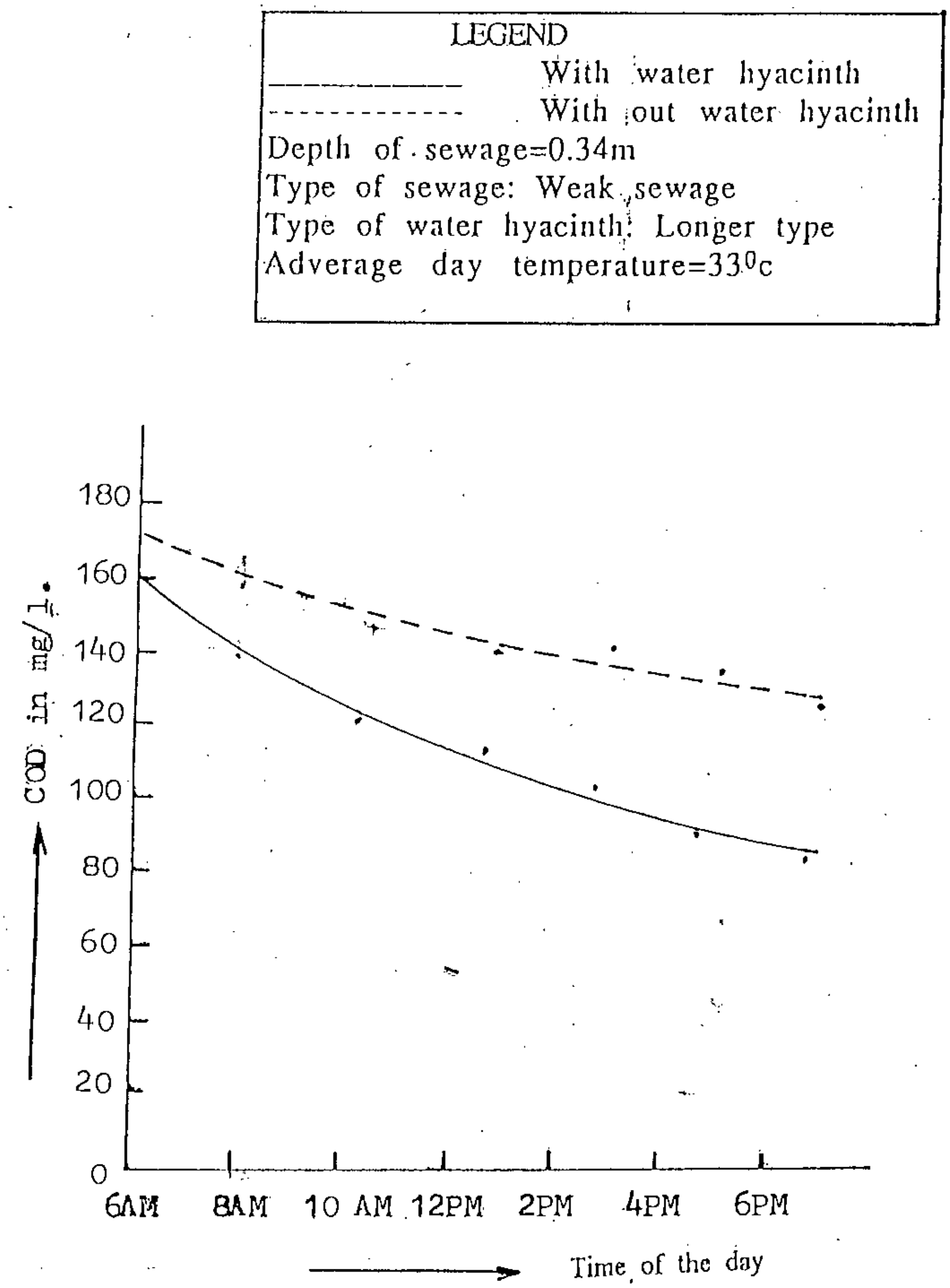

Fig . 5.8 Hourly COD removal in flowing condition.

Figure 5.8 shows hourly COD variation in flowing condition for the first 12 hours. From this Figure COD removal from sewage is 45% and 24% respectively for the water hyacinth and without water hyacinth. It is clear that in flowing condition removal of organic matter is more with water hyacinth but less in case of without water hyacinth than removal rate found in batch culture.

The above stated fact is clear from Fig. 5.8, which gives hourly COD variation in sewage with water hyacinth and without water hyacinth in flowing condition. The reasons for this difference in organic matter removal between batch culture and flowing condition may be due to:

01. In batch culture suspended solids and colloidal particle is adsorbed on the surface of roots of water hyacinth. But the surface area is not available for all the particle present in sewage. as a result partial treatment is done with the water hyacinth. On the other hand SS and heavier particle present in sewage does not adsorb initially with the roots of water hyacinth in flowing condition. Rather all these particles strike with the roots, the direction of velocity path changes, resulting quick settlement of heavier particle and SS. Finally some portion of organic matter is adsorbed on the root surface. Thus removal of organic matter by sedimentation is more in flowing condition than in batch culture, where water hyacinth is used.

02. In batch culture velocity of flow is zero. Particles which is heavier than water gets settle from the sewage due to gravitational action. Heavier particles settle quickly and lighter particle settle slowly in this condition but sedimentation is completed after a certain interval of time. On the other hand if there is no water hyacinth on sewage surface, except heavier particle, other particles can not settle in flowing conditions as it leaves the basin before completing settling path due to the flow velocity present in the basin.

LEGEND

___________	With water hyacinth
-------------	With out water hyacinth

Depth of sewage=0.5m
Type of sewage: Low concentrated
Type of water hyacinth: Longer type
Adverage day temperature=32.5^{0}c

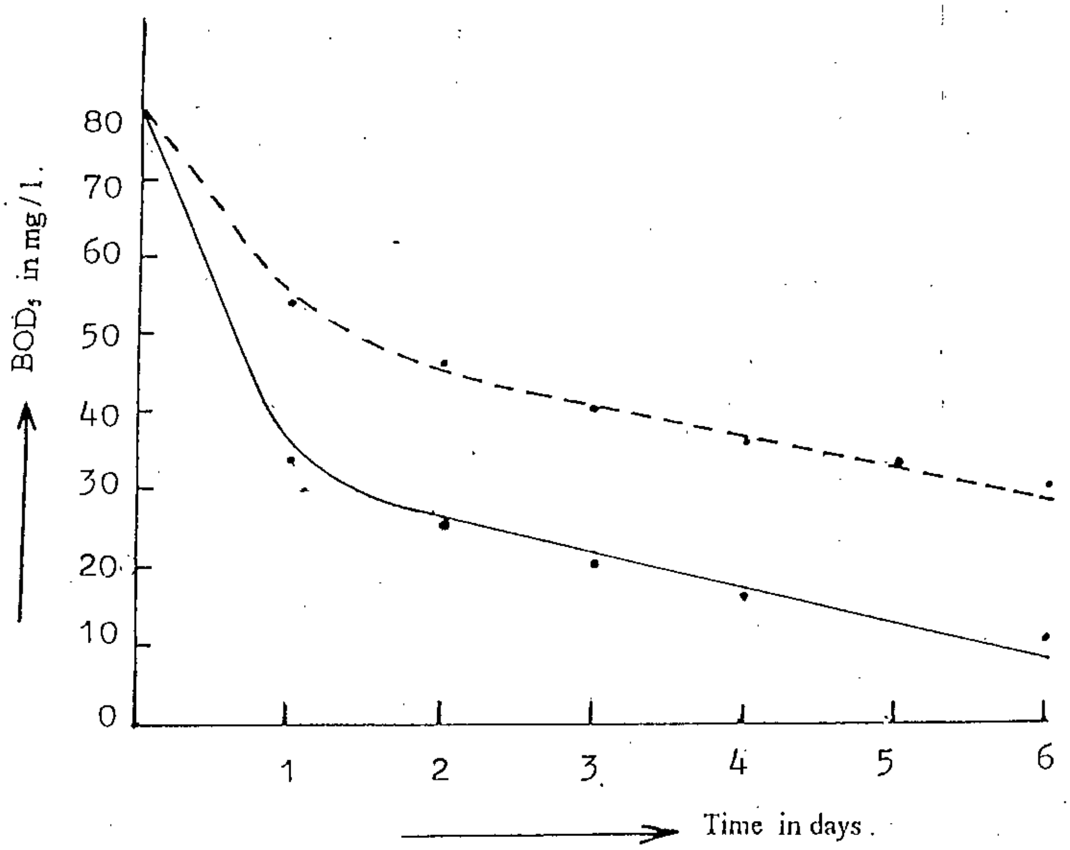

Fig. 5.9 BOD removal in flowing condition.

Thus removal by sedimentation is less in this case than in batch culture.

Figure 5.9 shows BOD removal from weak sewage in flowing condition. From Fig. 5.9 after 6 day BOD removal is 84% and 62% respectively with water hyacinth and without water hyacinth in flowing condition. Thus it is seen that removal of organic matter from weak sewage in flowing condition is more than medium dense sewage.

5.4.3 Influence of depth on removal of organic matter:

In this section removal of organic matter in flowing condition was determined in different depth conditions.

5.4.3.1 Experimental set up and procedure:

BOD and COD removal rate at a depth of 0.50 m and 0.17 m with and without water hyacinth were determined following the experimental set up and procedure described in section 5.4.2.1. At the end of each cycle run (after 6 day) sludge accumulated at the bottom of each basin was carefully measured. Initially the depth of sludge layer was taken and volume was calculated by multiplying this with the surface area. Test results found from this experiment are shown in Figure 5.10.

5.4.3.2 Results and Discussion

From Figure 5.10 BOD removal at a depth of 0.50 m with water hyacinth is seen 84% for a 6 day duration. In the same Figure BOD removal at a depth of 0.17 m is 90% in similar condition. Hence it is clear that organic matter removal with water hyacinth is more in shallower depth. The reason may be in flowing condition the anaerobic/aerobic interface fluctuates frequently due to the circulation of sewage and shallower depth.

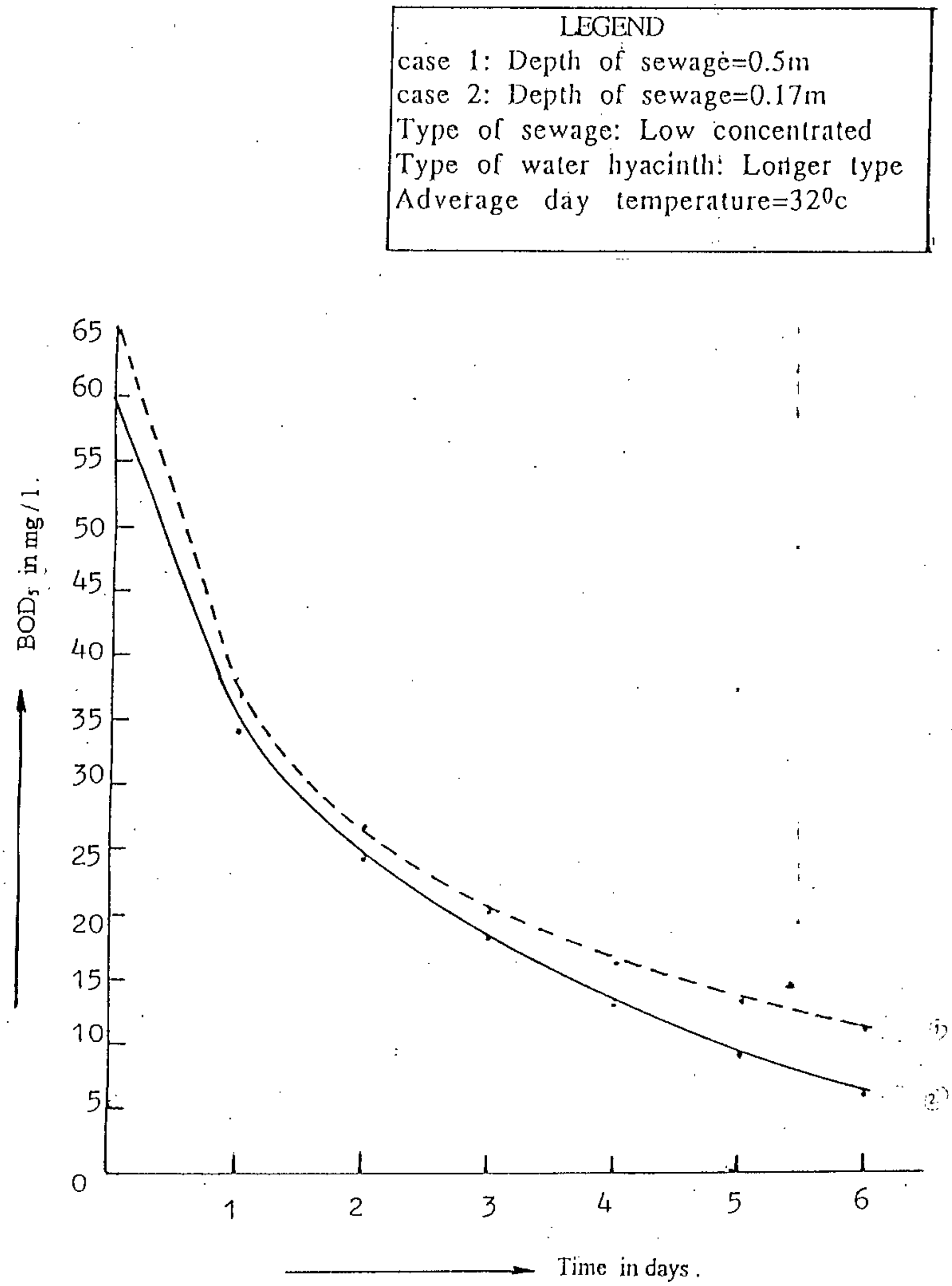

Fig. 5.10 BOD removal in flowing condition with water hyacinth.

Thus the system biology changes and aerobic condition prevails since aerobic ponds are often referred to as polishing or 'tertiary' ponds and anaerobic pond provides a partial treatment of a strong sewage. The BOD removal has been found more in flowing condition and shallower depth than in batch culture.

Whereas pilot scale study was conducted at Walt Disney. USA to treat effluent from conventional primary sedimentation ponds with water hyacinth. The loading was 42 kg BOD_5/acre/day and the water depth was 0.38 m. Initial BOD_5 of waste water was 134 mg/l. This hyacinth pond produced an effluent BOD_5 of approx. 28 mg/l during the first month of operation in August 1979. BOD_5 reduction was 79% from hyacinth pond (Kruzic, 1979).

The removal of organic matter found in this study is higher than the study performed at Walt Disney, USA. The reason may be that Author's study was conducted in more controlled condition than the pilot scale study at Walt Disney. In addition influence of temperature and climatic condition may be another reasons for higher removal rate in this study.

In addition, from the experiment conducted it is observed that among the total sludge about 60% sludge accumulated in the first basin, 25% in the second and only 15% in the third basin. It indicates that removal of SS and heavier particle occurs during the first phase and reduction is less in the subsequent operations. as a result organic matter removal within first 24 hours is rapid.

In waste stabilization ponds BOD removes according to the equation (2.1), as given in literature review. In this study it has been found that BOD removal in pond system does not follow equation (2.1). The reason is that during the first two days most of the organic matter removes due to the sedimentation process. After 2nd days of the treatment BOD removes by the biological activity of the water hyacinth and oxidation process of the micro-organism. The portion of BOD removal which is oxidized by the micro-organisms, follows the BOD removal kinetics i.e satisfy equation (2.1). Some portion of the organic matter get attached with the roots of water hyacinth which also reduces the BOD leading in the water hyacinth pond system.

5.5 COMPARISON OF COST ESTIMATES BETWEEN SEWAGE TREATMENT IN POND SYSTEM WITH AND WITHOUT WATER HYACINTH:

In this section operating costs for sewage treatment in ponds system has been discussed.

5.5.1 Introduction:

Cost is an important parameter in sewage treatment. Under favourable climatic conditions sewage treatment with water hyacinth is feasible and economical. Total cost for the sewage treatment includes initial cost investment, cost for process treatment and maintenance cost. Among these major cost is involved in sewage treatment process. Treatment cost depends on the sewage type climatic condition, plant efficiency and the effluent quality. For the same type of sewage sample, under same climatolagical condition and for a given effluent stand, detention time will different between pond systems with water hyacinth and without water hyacinth. Detention time is the controlling factor for treatment cost, longer the detention time, larger the pond size i.e. the treatment cost will be higher. In this section various sewage samples have been analysed to find out the detention times of ponds with and without water hyacinth for the same degree of purification.

5.5.2 Estimate of detention time of ponds for the same effluent quality:

Generally in both the systems (with water hyacinth and with out water hyacinth) initial organic removal is dominated by sedimentation characteristics. The remval characteristics in later stage is mostly for biodegradation. This bio degradation process is the break down of organic matter by the micro-organisms which depends on the removal reaction rate constant. A typical analysis to estiamte rate constant and detention time of ponds is given below.

Removal rate constant (k) of a sample having mitial BOD_5 = 110 mg/l was estimated for conventional pond system using thomas method (Metcalf & Eddy Inc. 1979). The values of k was estimated as 0.11 d-1 it is observed that the effluent quality of conventional pond systems after 6 day was (BOD_5 of sewage) 43 mg/l. Using equation 2.1 ultiamte BOD was determined as 216 mg/l.

For the same sewage sample the effluent quality after 6 day treatment with water hyacinth system was obtained as BOD_5 = 30.0 mg/l. For the same effluent quality in conventional pond system (using equation 2.1) detention time can be estimated as

$$t = \frac{1}{k} \left(- \log_{10} \frac{L_t}{L}\right)$$

$$= 1/0.11 \ (- \log10 \ \ 30/216)$$

$$= 7.5 \text{ days}$$

Similar analysis have been performed with sewage samples having initial BOD_5 of 180 mg/l, 100 mg/l, 80 mg/l, 75 mg/l and 70 mg/l and are tabulated below.

Table 5.2: Detention times for the pond systems for the same effluent quality

Sl. No.	Initial BOD_5 mg/l	Desire effluent BOD_5 mg/l	Detention time in days	
			With water hyacinth	Without water hyacinth
1	180	45	6	ee
2	110	30	6	7.5
3	100	26	6	7.5
4	80	5	6	8.0
5	75	19	6	7.0
6	70	17	6	7.5

5.5.3 Summary and Conclusions:

From the analytical data given in Table 5.2, it is well understood that for the equal flow rate and same sewage sample in both the ponds (with water hyacinth and without water hyacinth), longer deterntion time is required for the pond system without water hyacinth to dicharge same effluent quality. Generally 25% higher detention time has been found in pond system without water hyacinth than with water hyacinth. Since treatment cost is higher for longer detention time, treatment cost in ponds with water hyacinth will lower than without water hyacinth ponds.

Capital cost for both the ponds is same only water hyacinth pond requires slightly higher maintenance cost. If water hyacinth from the ponds system can properly utilized, than the benefit from this system will overcome the additional maintenance cost. Finally it may be concluded that water hyacinth pond system is economical and produces better effluent quality than ponds without water hyacinth system.

5.6 REMOVAL OF NITROGEN, PHOSPHOROUS, SUSPENDED SOLID AND TURBIDITY FROM SEWAGE WITH AND WITHOUT WATER HYACINTH

In this phase of study sewage samples were run into the flow arrangement as described in section 5.4, were in order to determine removal rate of nitrogen, phosphorus, suspended solid and turbidity from sewage after certain interval of time.

5.6.1 Materials and Method:

Water hyacinth:

Water hyacinths were collected from the canal, located between Tejgaon industrial area and Mohakhali, Dhaka. Longer root, larger stem size and rapid growth indicates enough nutrient present in wastewater. Other characteristics of water hyacinth is as follows:

Total height	:	1.15 m
Height of stem	:	0.96 m
Length of roots	:	180 mm
Leaf surface area	:	0.016 m^2

Sewage sample:

About 700 liters of sewage sample were collected from main sewer line of Dhaka WASA at 8 A.M. In addition 200 litre of strong sewage from a bore hole were mixed with this sewage, in order to increase the concentration, and nutrient contents of earlier sewage. Some physical characteristics of this mixed sewage is as follows:

pH	:	8.0
Turbidity	:	140 NTU
Temperature	:	29°C
Color	:	Light gray
COD	:	160 mg/l

Flow Arrangement:

Similar flow arrangement as described in section 5.4.3 was used for the experiment.

5.6.2 Removal of Nitrogen:

In this section nitrogen removal rates with water hyacinth and without water hyacinth from sewage were determined after certain interval of time in flowing condition.

5.6.2.1 Experimental set up and Procedure:

To conduct the experiment similar set up was used as described in section 5.4.3. In this experiment sewage sample (as described in section 5.2) were run through the series of basin. Experiment was conducted in two cycles. In one cycle water hyacinths were used for removal of nitrogen from sewage. In another cycle, no water hyacinths were used.

Sewage samples from the basin were collected in clean glass bottles everyday at 8 AM and transported to the environmental engineering laboratory, in BUET, for determination of total nitrogen content.

From the sample collected total 'Kjeldahl' nitrogen were determined in the laboratory. To determine total 'Kjeldahl' nitrogen, organically bound nitrogen in sewage sample was converted into ammonia salts by the action of sulphuric acid and hydrogen peroxide. The ammonia was then analyzed by a modification of the Nessler method.

HACH Digestal digestion apparatus was used for digestion of the sewage sample. The digestion was done according to the standard laboratory procedure. The results are given in tabular form in Appendix B and are shown in Figure 5.11.

5.6.2.2 Results and Discussion:

As seen in Figure 5.11, tremendous amounts of nitrogen is consumed by the water hyacinth from sewage during the experiment. But in case of without water hyacinth system, nitrogen disappears from sewage in a slower rate. from this Figure it is seen that difference between case 1 & 2 becomes higher after each day. In this case maximum difference is seen after 6 day. It indicates that nitrogen removal rate form sewage

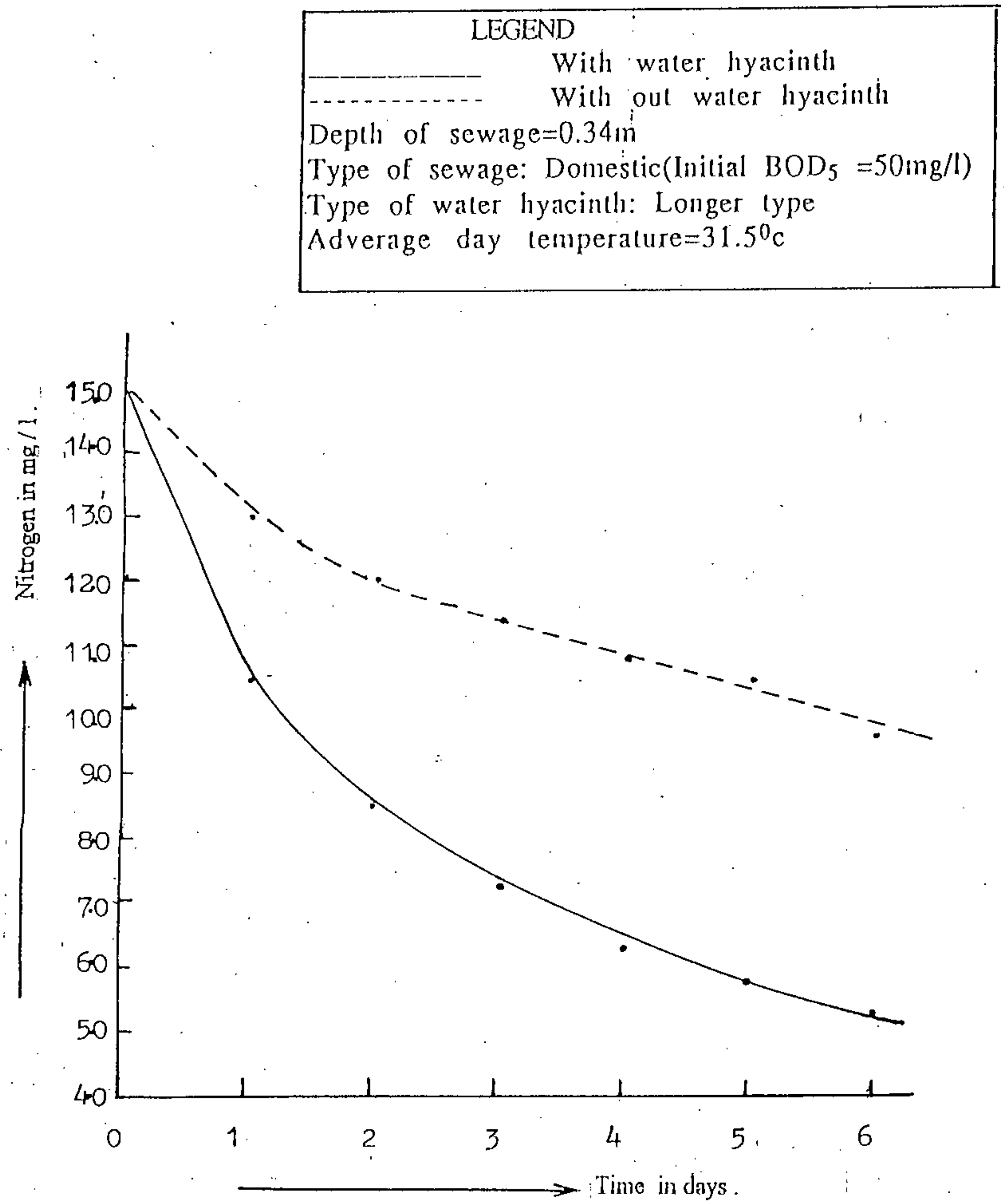

Fig. 5.11 Variation of nitrogen loading in sewage at different days.

with water hyacinth becomes higher than from sewage without water hyacinth, as the detention time increases.

With the use of water hyacinth, nitrogen removal of 30% in 24 hours and 65% after 6 day has been found. Average removal is increased by 5% in this case. On the other hand average nitrogen removal from sewage without water hyacinth is seen in case 2. In this case 13.5% Nitrogen is removed after 24 hours and 35% after 6 day treatment. It is clear that up to 5 day duration nitrogen removal rate from water hyacinth system is about two times than removal rate from without water hyacinth system. After 6 day difference of removal between the two system is 30%.

Reasons for the stated difference are narrated below:

01. Like organic matter removal, Nitrogen removal with water hyacinth is more as because sedimentation, adsorption and absorption by roots of water hyacinth is more than without water hyacinth system.

02. Nitrogen and phosphorus are key nutrients for growth of water hyacinth and in biological treatment processes where there is a net production of bio mass, a certain amount of these materials is removed by assimilation into the bio mass. Water hyacinth takes up large amount of Nitrogen and phosphorus as a consequence of the growth requirements.

03. Nitrification process is one of the major nitrogen removal process. Denitrification occurs in absence of oxygen. For a certain period water hyacinths lowers the DO of the liquid. This improves the environment for denitrification process. In addition bacteria attached with the roots of water hyacinth promotes denitrification process.

5.6.3 Removal of phosphorous:

Phosphorus in the form of organically bound compound is mainly removed from sewage by water hyacinth. Other forms of inorganic phosphorus precipitates and removes from sewage by the sedimentation process. In this section removal of phosphorus from sewage sample with water hyacinth and without water hyacinth is determined.

5.6.3.1 Experimental set up and procedure:

Same experimental set up as described in section 5.3 was used for determination of phosphorus removal. For conducting phosphate test in the laboratory, sewage sample from the basin were collected in cleaned glass bottles that have been cleaned with 1:1 hydrochloric acid solution and rinsed with distilled water. Phosphate contents were determined in the environmental engineering laboratory, BUET from these sample. Ascorbic acid method using phosver 3 phosphate reagent for wastewater was used for this determination. The recorded results are given in tabular form in Appendix B and are shown in Figure 5.12.

5.6.3.2 Results and Discussion:

Fig. 5.12 gives the phosphorus contents of sewage sample at various days during the experimental period. From this Figure it is seen that removal of phosphorus is small in comparison to the removal of other pollutants in sewage. This is may be due to the fact that water hyacinth can not take up additional phosphorus for their growth requirement, only partial amount of total phosphorus is utilized.

From Fig. 5.12 after 24 hours, removal rate of phosphorus from sewage is 20% and 9% respectively with water hyacinth and without water hyacinth. after 6 day removal of phosphorus with

LEGEND

______________	With water hyacinth
- - - - - - - - - - - -	With out water hyacinth

Depth of sewage=0.34m
Type of sewage: Medium dense
Type of water hyacinth: Longer type
Adverage day temperature=33^{0}c

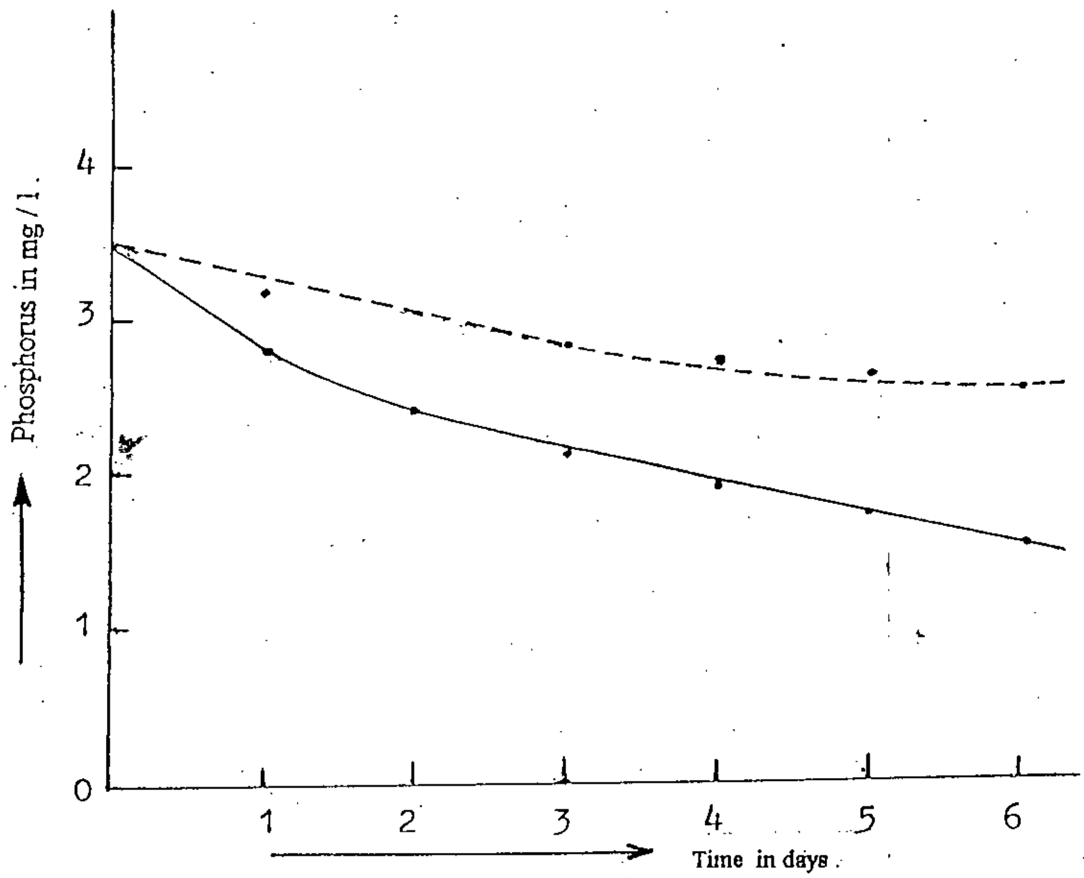

Fig . 5.12 Variation of phosphorus loading in swage at different days .

water hyacinth is 57%. On the other hand without water hyacinth phosphorus removal is 29% from sewage. Thus it is clear that removal performance found by water hyacinth is excellent in sewage treatment.

Similar study was conducted in Florida, USA. Here primary sewage was treated with water hyacinth with a 6 day hydraulic retention time. Depth of liquid was 0.60 m. Nitrogen and phosphorus reductions was up to 80% and 50% respectively from this pond (Reddy and Debusk, 1987). Higher nitrogen removal and lower phosphorus removal is seen in that study than author's study. Detail process and environment for sewage treatment with water hyacinth in Florida is unknown to the author. Thus the reasons for differing experimental results can not explained.

5.6.4 Removal of Turbidity and suspended solids:

Suspended solids present in sewage is considered as a pollutants in some extent. In this section removal of suspended solids and turbidity from sewage during the experimental schedule is reported.

5.6.4.1 Experimental set up and procedure:

Removal of SS and turbidity from sewage was determined from the experimental set up for N & P removal (as described in section 5.3). From same sewage sample collected for N & P determination in the laboratory, Turbidity and SS contents were determined.

Sample collected from the basins at regular interval were transported to the environmental engineering laboratory in BUET for determination of SS and turbidity of sewage sample. Turbidity were determined with the help of HACH model 16800 portland turbidity meter. This equipment provides facilities for determination of turbidity only up to a limit of 100 Nephelometric turbidity units (NTU). But in most cases the turbidity of sewage samples were diluted with double distilled water to a certain percentage so that turbidity of this mixed sample remains within 100 NTU. Turbidity of original sample is determined by multiplying the results from mixed sample with dilution factor.

Suspended solids of the sewage sample were determined using the standard laboratory procedure. The results are shown in Figure 7.13 and 5.14.

5.6.4.2 Results and Discussion:

From Fig. 5.13 is clear that removal of turbidity form sewage with water hyacinth is best suited than without water hyacinth. In this experiment turbidity removal of 65% and 35% have been found with water hyacinth and without water hyacinth respectively after 6 day. Thus it is clear that turbidity removal performance from sewage with water hyacinth is excellent in comparison to removal rate from without water hyacinth system. The difference of removal between water hyacinth and without water hyacinth system may be the effect of turbulence, roiling and wind action. Use of water hyacinth on sewage sample prevents the turbulence and roiling by wind action. Turbidity of sewage is reduced rapidly and maintain the improved condition by water hyacinth, resulting higher removal rate.

From Figure 5.14 it is clear that water hyacinth is best suitable in removing SS from sewage, especially form shallower depth. as seen in Fig. 5.14 SS removes from sewage in uniform rate if no water hyacinth is used. But tremendous SS is removed by the water hyacinth during first 24 hours. Case 1 shows SS level found in sewage with water hyacinth. Faster reduction of SS level in sewage after two days has been observed. About two third of the suspended solids is removed after two days with water hyacinth. This is because water hyacinth acts as a polisher in flowing condition. SS is removed by the filtration

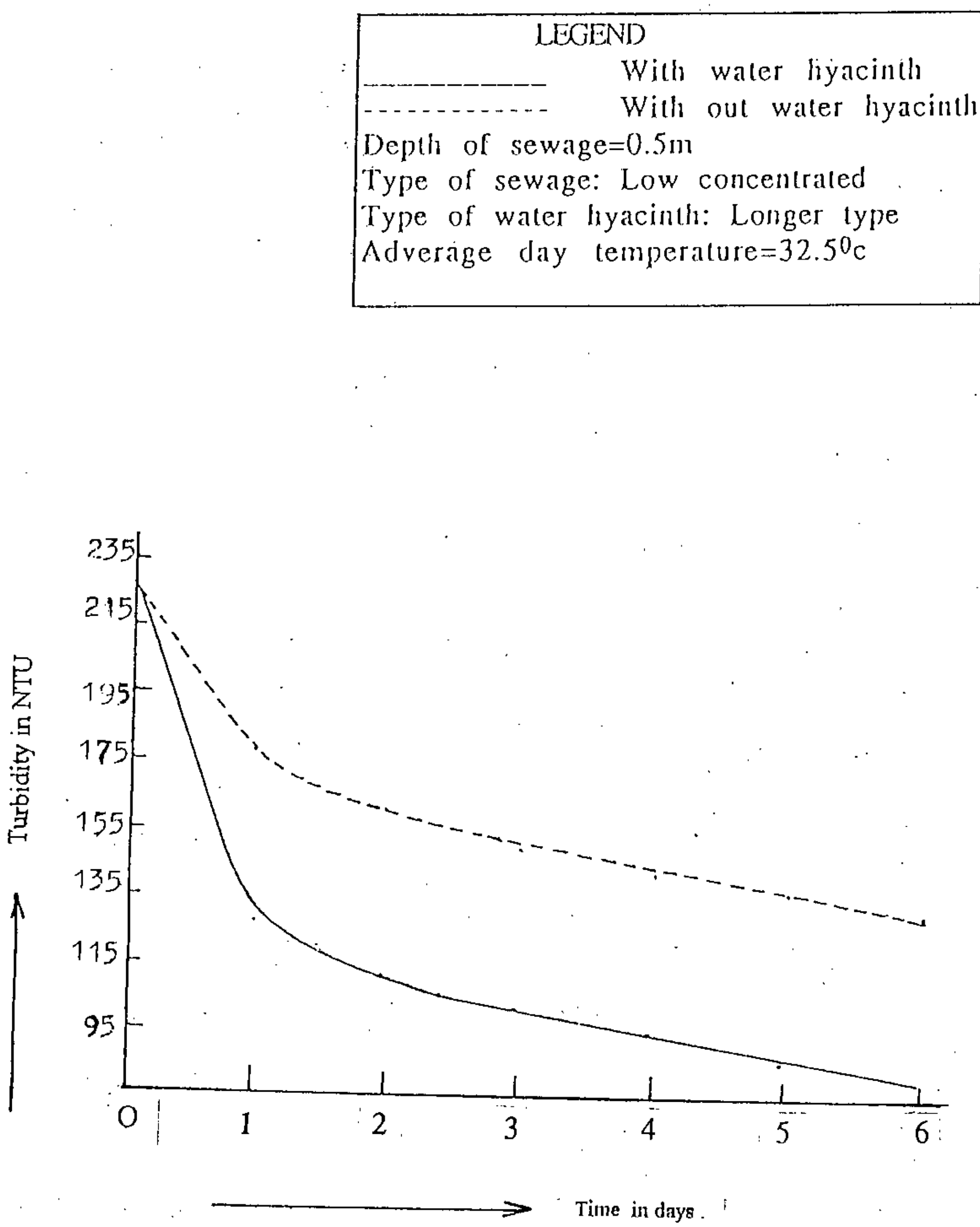

Fig . 5.13 Variation of turbidity in swage at different days .

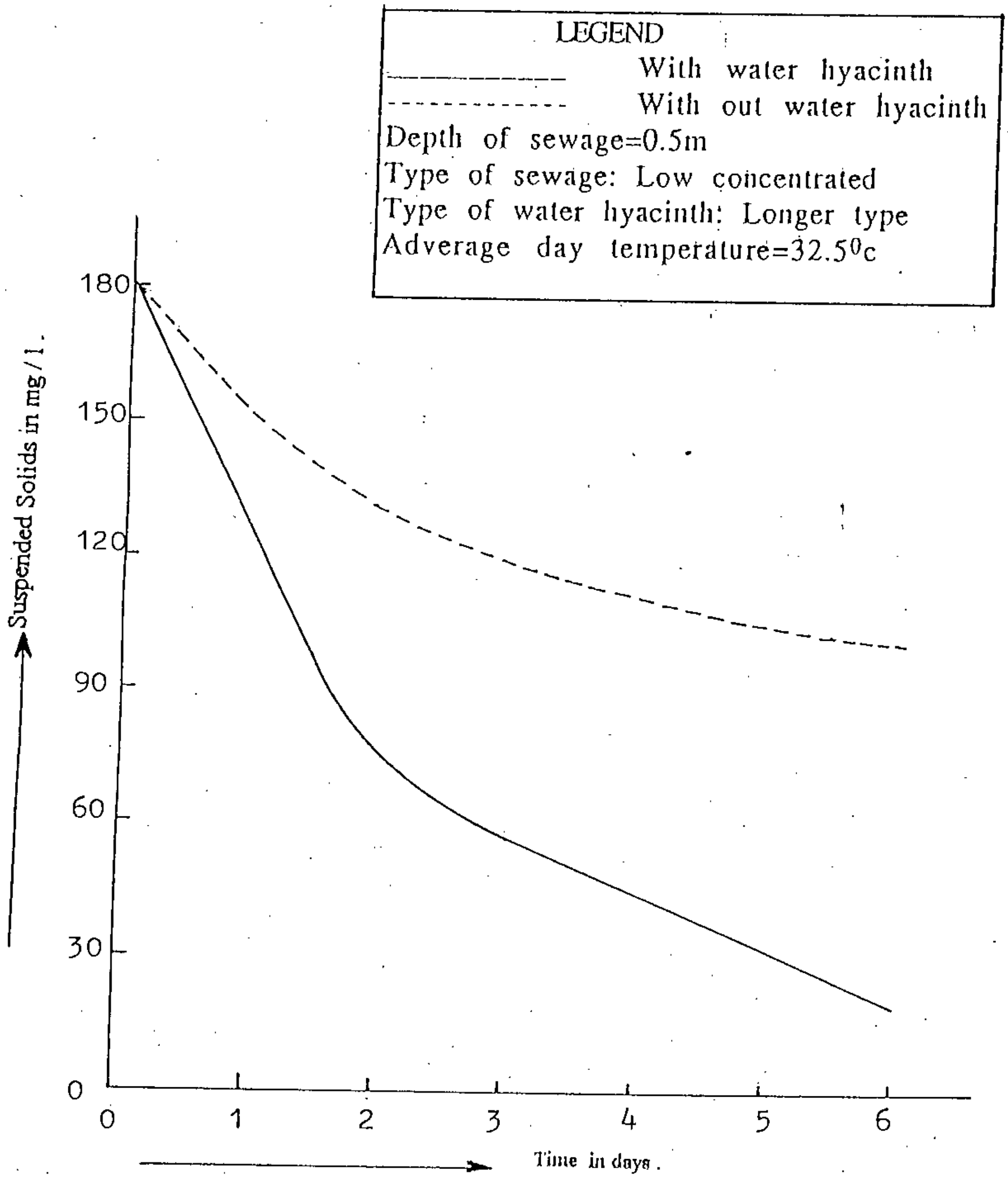

Fig. 5.14 Variation of suspended solids in swage at different

process due to the presence of long roots of water hyacinth in the sewage column. In this experiment SS removal with water hyacinth is 89% and without water hyacinth 43% after 6 day.

Due to the shortage of time, SS removal rate with the variation of depth and percentage coverage could not studied. Since the removal of SS in shallower depth is considered to be higher.

Similar removal rate is observed from different studies conducted in USA. At Walt Disney, pilot scale hyacinth ponds produced an effluent TSS of about 135 mg/l. Reduction of SS in this case was 83% (Kruzic, 1979). In florida, two facilities for waste water treatment with water hyacinths were observed. Preliminary results reported from these two facilities indicate that a final effluent can be produced in water hyacinth ponds which will meet advanced waste treatment standards for TSS (Stewart, e.A, 1979). This indicate that TSS removal will be more than 80% from sewage.

5.7 SUMMARY OF FINDINGS:

01. In general removal rate of organic matter from sewage with water hyacinth is 10% more than without water hyacinth system in batchculture.

02. Mostly removal of pollutants occur during the first 24 hours due to the sedimentation process.

03. Removal of organic matter with water hyacinth is affected by the sewage concentration. For a total detention time of 6 day, removal rate decreases with the increase in sewage concentration.

04. Removal of organic matter with water hyacinth in flowing condition is more than those found in batch culture. In flowing condition, removal of organic matter with water hyacinth from medium sewage is 9% higher than in batch culture for the same condition. In case of weak sewage 84% removal of organic matter has been found, which is about 10% higher than in batch culture.

05. In flowing condition organic matter removal is about 90% after 6 day from low cost sewage, at a depth of 17 m, with watrhyacinth.

06. Difference of removal rate between water hyacinth and without water hyacinth in flowing condition is higher. Here removal rate of organic matter with water hyacinth is about 22% more than without water hyacinth.

07. After 6 day, removal of total nitrogen from sewage is about 65% in case of water hyacinth system and 35% in case of without water hyacinth system.

08. Limited phosphorus is removed by water hyacinth. Combining all the process involved in water hyacinth pond only 57% removal of phosphorus is found from this system after 6 day.

09. Water hyacinths present in the pond system polishes the effluent sewage through filtration and adsorption process with the longer root system. In this study reduction of SS and turbidity is seen 89% and 65% respectively with water hyacinth.

CHAPTER 6

NUISANCE PROBLEM, SUMMARY OF STUDIES AND PRELIMINARY DESIGN GUIDE LINES

6.1 INTRODUCTION

In this chapter Author examine aspects of the study on a more general basis, recognition that preliminary discussion of experimental work has already been included within previous chapters. Particular attention is developed to the preliminary design guide lines for sewage treatment in water hyacinth ponds.

6.2 NUISANCE PROBLEM IN WATER HYACINTH POND SYSTEM

The term 'nuisance' is any thing that interferes with other legitimate users of the water resource, air, and disturbs environment. Legitimate use here does not merely include man made laws such as those govern in public health industrial abstraction/discharge or amenity but more fundamentally, encompasses natural laws of ecology and its supporting science.

Nuisance have been rated as the first concern of the public relative to the implementation of sewage-treatment facilities. within the past few years, the elimination of odors and mosquito breeding control have become a major consideration in the design and operation of sewage treatment facilities by water hyacinth ponds, especially with respect to the public acceptance of these facilities. The importance of odors in human terms is related primarily to the psychological stress they produce rather than to the harm they do to the body. In many areas, projects have been rejected only because of the potential.odors.

But from different study and observation it is seen that water hyacinth system creates very little odor if it is properly designed and handled. Followings are the observational reports from different study.

01. Odors in sewage usually are caused by gasses produced by the decomposition of organic matter. Fresh sewage has a distinctive, some what disagreeable odor, which is less objectionable than the odor of stale of septic sewage. The most characteristics odor of stale or septic sewage is that of hydrogen sulfides. In water hyacinth pond aerobic condition is maintained by providing shallower depth, diffused air and supplying oxygen by the photosynthetic activity of water hyacinth. In this study odor was released only at the time of filling basins with sewage sample. Odor in other times was measured by sensory methods. No odor was reported at that time.

Mosquito and fly breeding was observed in this study. Mosquitos were found in water hyacinth earthen tubs at day time where sewage sample were in stagnant condition. No mosquitos or fly were found in rectangular basins under flowing condition. Thus it is clear that mosquito problem may be controlled partially by maintaining flow condition and harvesting water hyacinth at regular interval.

02. Discharge of raw sewage directly into the water body has been found in many areas of Dhaka city. One of such out fall for discharge of sewage is located at Banani, Dhaka, as shown in Fig. 6.1. Sewage is discharged in lakes, where dense water hyacinth growth is seen at out let area. Nuisance condition at this place was noted.

No odor was released from this place, but presence of mosquito was found. This is because water is in stagnant condition and harvesting of water hyacinth is totally absent. Another point to be noted from this place that growth of water hyacinth around the out let area is more and strong in comparison to water hyacinth located far distance from outlet point. This is clearly seen in Fig.6.2. Uptake of nutrients & other pollutants by water hyacinth from sewage is distinct at this point. From this observation it is clear that water hyacinth does not

Fig. 6.1 Sewage discharges into lakes at Banani(Dhaka).

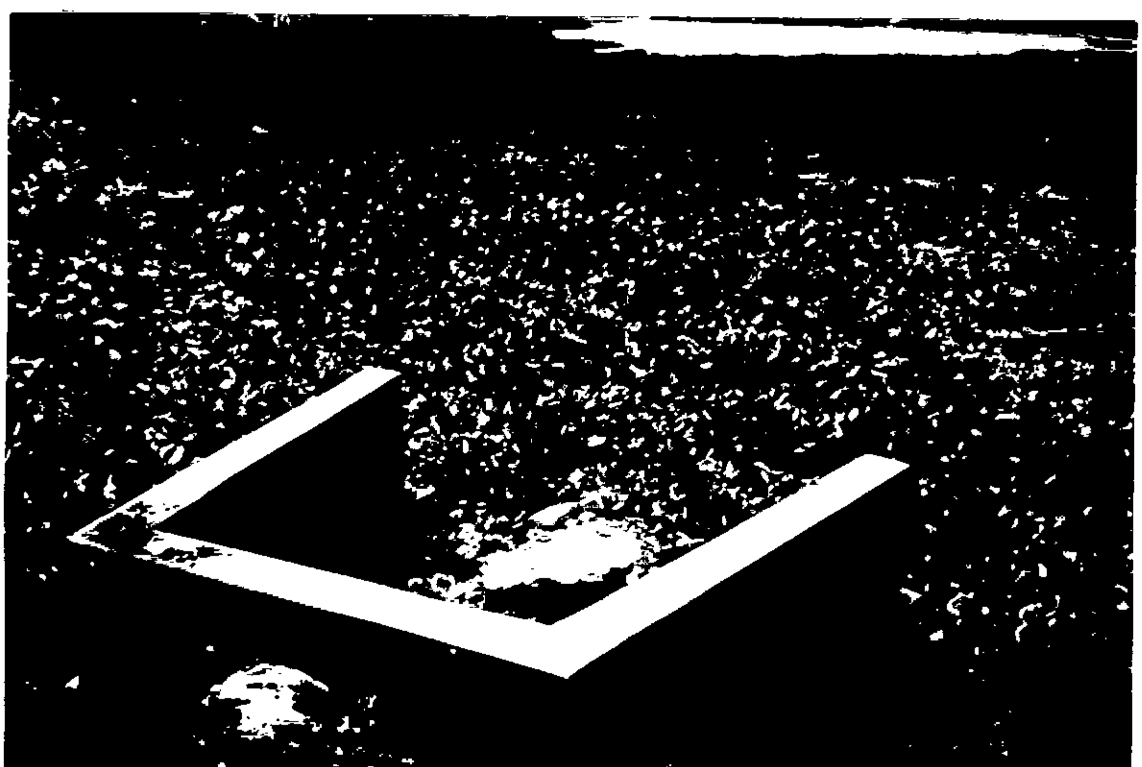

Fig. 6.2 Dense water hyacinth growth around sewage discharges outlet.

creates only nuisance to the environment, but it improves the environmental conditions also. Water hyacinth helps in the bio-degradation of organic matter, consumes tremendous amounts of pollutants from sewage and finally produces better effluent quality.

6.3 SUMMARY OF STUDIES

Table 6.1 summarizes design and performances from different studies. Pollutants removal rate found in three different studies conducted in U.S.A is given in this Table. Performance of authors study is also included in this Table. From Table 6.1 it is seen that pollutants removal rate is higher in ponds system with water hyacinth than without water hyacinth system. The removal rate is more in authors study than others. This indicates that water hyacinth can be used effectively in removing pollutants from sewage in this country.

6.4 PRELIMINARY DESIGN GUIDE LINES

Very little information on the design and performance of aquatic systems as a function of design variables, sewage quality, and environmental factors is available. In the absence of information necessary for the development of rational design criteria, the purpose of this section are to present significant data from currently conducting study, to suggest preliminary design guidelines for removal of pollutants in sewage using water hyacinth.

Pre-treatment

If organic loading(BOD_5) is more than 110mg/l in the influent sewage concentration, then water hyacinth will die. The treatment system may fail. Presence of heavy SS in the influent sewage concentration may increase treatment cost. In such a condition provision of primary sedimentation in separate pond is required, so as to reduce the loading in the water hyacinth system. Detention time of 24-48

Table 6.1 Summary of Different Studies

Sl. No.	Location	Type of pretreatment	Detention time (day)	% BOD removal	% SS removal	% Total Nitrogen removal	% TP removal
1	National Space Technology lab:(Wolverton B.card Md Donald R.C, 1979) Without water hycinth With water hycinth	None	54	81	30	47	27.5
2	Luccdale,Missicipie, (Wolvrton B.C and McDonald R.C. 1979) Without water hycinth With water hycinth	None	44	55 85	45 95		

3	Orange Grove, Missicipie, (Wolvorton B.C and Mc Donald R.C (1979) Without water hyacinth With water hyacinth	Two-aerated, three facultative lagoons in parallel	7	 26 72	 50 67		
4	BUET, Bangladesh Author's study) without water hyacinth With water hjyacinth	None	6	58-64 64-90	43 89	35 65	28 57

hours is preferable in this pond. Since maximum sludge will settle in this pond, depth should be sufficient to contain the solids that will accumulate between cleanings.

Water hyacinth

Longer root water hyacinth having longer stem system is best suitable to treat sewage in pond system.

Detention time

Six day detention times in such water hyacinth pond is capable enough to remove 90% pollutants in sewage. From different study it is seen that after 3 day removal rate becomes slower and after 6 day removal is quite smaller. Thus after 6 day sewage treatment may not be economical.

Process Flow Diagram

It has been observed that the effluent from a series of ponds is of better quality than that from a single pond of the same size. This is because although the hydraulic regime in individual ponds is closer to complete mixing than it is to plug flow, the over all performance of a series of ponds approximates that of a plug flow reactor. Water hyacinth must be used in series of pond systems providing tertiary treatment.

The quality of the final effluent from these systems improves with complexity of the facility. Process flow diagram for water hyacinth system designed to produce advanced secondary or tertiary effluent is shown in Figure 6.3.

Gravitational flow from primary sedimentation basin and falling from some height in thin layer will provide additional facilities for increasing DO level in sewage. in addition, diffused air can be injected at the outlet end by mechanical air diffuser to improve the aerobic condition in sewage. The hyacinth drying areas shown in Fig. 6.3 is simply impervious area which is sloped so that water is released.

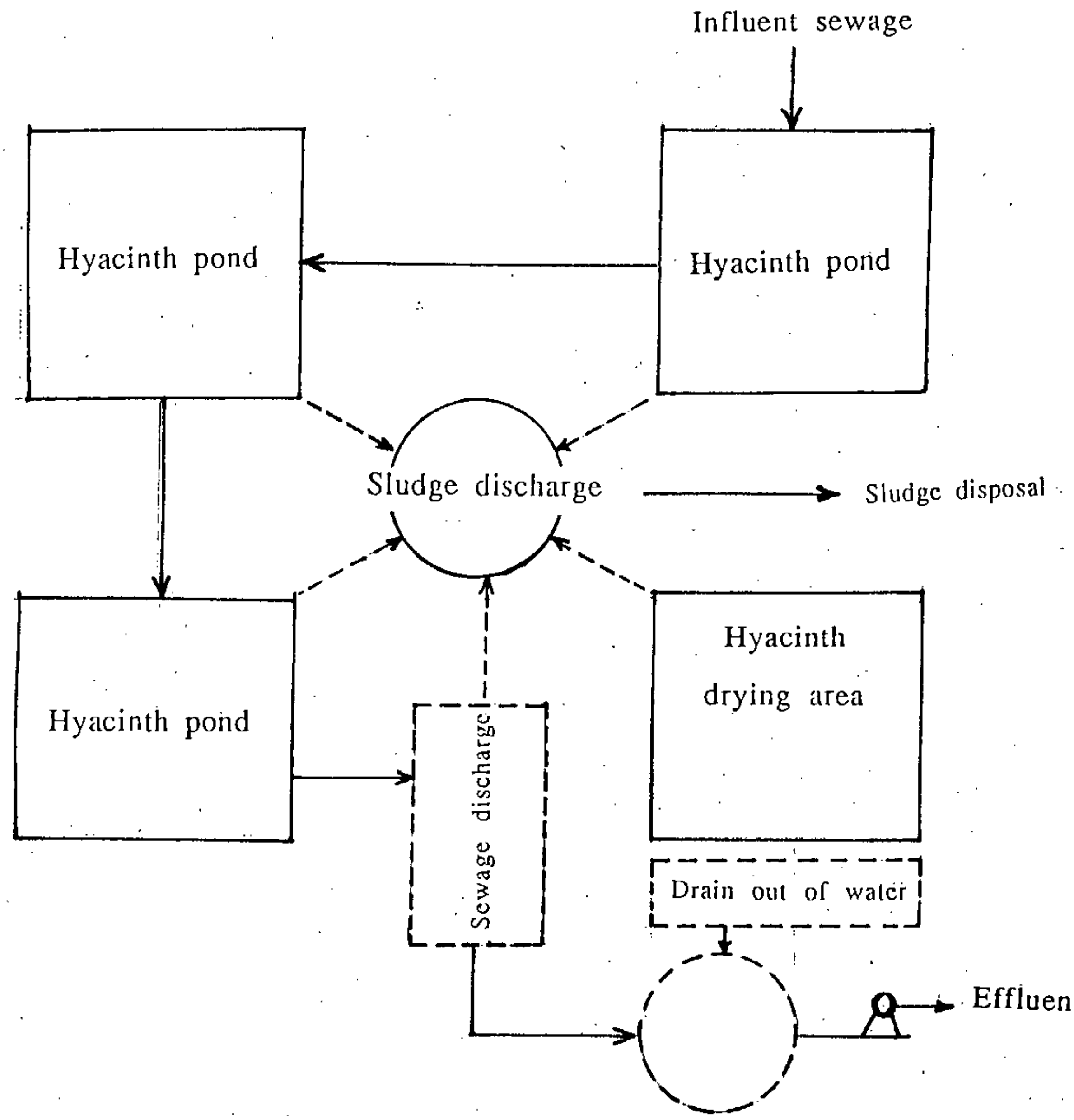

Fig. 6.3 suggested process flow diagram for sewage treatment in pond system.

Depth of pond

Shallower depth is always preferable in water hyacinth pond. Maximum depth should be 0.4m. so that water hyacinth maintain free floating on sewage sample and roots of water hyacinth can serve as a filter media. Maximum depth is 1m so as to maintain aerobic condition.

Length/Width ratio

The BOD load to a water hyacinth pond system should be applied in such a manner as to not cause either hydraulic short-circuiting or aesthic problems. Short-circuiting can be prevented by designing pond system to have geometrics with large length to width ratios that distribute sewage flow across the ponds uniformly. A length to width ratio of at least three has been recommended.

Mosquito Control

Fly and mosquito breeding is a problem in water hyacinth ponds but this can be partially alleviated by introducing larvae-eating fish species such as *Gambusia* and *peocelia* into the ponds. Also frequent harvesting of water hyacinth and maintenance of continuous flow, disinfection at the outlet end may negotiate this problem.

Plant harvesting

The frequency of plant harvesting will determine whether the process shown in Fig. 6.3 is used to provide advanced secondary or tertiary treatment. Maximum nutrient removal is achieved in shallower ponds which are harvested frequently. It may be further explained in the following manner.

The nutrient assimilation capacity of water hyacinth is directly related to growth rate, standing crop and tissue composition. water hyacinth was found to reach a standing crop level of 30 tones(dry weight)/ha in Florida, resulting in a maximum storage of 90 kg N/ha and 180 P/ha (Reddy and Debusk 1987). Thus harvesting of older plant each in a week will allow new plants to growth rapidly resulting more pollutant removal.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

Water hyacinth is an aquatic plant having prolific growth and is considered as a nuisance to environment, a health hazard to man and danger to other species of aquatic flora and fauna. Many measures have been taken for the destruction of the plants. However, the robust plant continue to survive and multiply and has established it self as a stable components of aqueous ecosystems of the tropical and subtropical regions. This research work has been directed towards evaluating various aspects of water hyacinth, in pollutants removal from sewage and economic utilization of water hyacinth.

Survival condition and growth rate of water hyacinth in different sewage sample have been studied. Experiments have been conducted in this study to determine the evapotranspiration and evaporation rate of sewage with and without water hyacinth. A number of experiments have been performed to determine the pollutants removal rate from sewage with and without water hyacinth. Removal of pollutants with water hyacinths have been found more effective for sewage treatment in pond system than similar pond system having no water hyacinth. In conventional sewage treatment system, longer detention time is required for sewage treatment than water hyacinth pond system. This indicates that water hyacinth pond system will provide lower treatment cost. Conclusions that con be summarize from this study is presented in the following section.

7.2 CONCLUSIONS

The principal Conclusions of the study are listed as follows:

1. Apparently water hyacinth creates nuisance to the environment. From different investigations it is seen that water hyacinth up grade waste water quality which is discharged into waterbody and improves the environmental condition.

2. For the same degree of purification and sewage characteristics about 25% more detention time is required for sewage treatment in ponds system than ponds with water hyacinth system.

3. Nitrogen and SS removal of 65% and 89% have been found in ponds with water hyacinth in comparison to 35% and 43% in ponds without water hyacinth for a 6 day detention time.

4. Organic matter present in sewage is removed in a higher rate in ponds with water hyacinth than ponds without water hyacinth. In general removal of organic matter has been found 64% -90% in ponds with water hyacinth and 58%-64% in ponds without water hyacinth for a 6 day detention time.

5. Evapotranspiration from water hyacinth covered sewage has been reported from 2.2 times to 4.5 times greater than evaporation from open sewage under the same climatological condition. Higher Evapotranspiration rate reduces the sewage volume rapidly which helps in case of sewage handling.

7.3. RECOMMENDATIONS FOR FURTHER STUDY

01. Use of water hyacinth is best suited in summer. Maximum growth rate and removal rate is found during this period. But growth rate becomes slower or ceases during winter. Further study is required to determine the pollutant removal and evapotranspiration rate in winter.

02. Due to the limited scope of time in this study, removal of N & P from sewage with different conditions could not perform. Further study is recommended to find out a best suitable environment for maximum removal of nutrients from sewage with water hyacinth.

03. Further study is needed to determine the removal performance of heavy metal, specially incase of Pb, Cd, and Zn.

04. Denitrification occurs in the absence of dissolved oxygen when nitrates formed earlier are reduced to nitrogen gas and given off to the atmosphere. But denitrification to occur, prior nitrification is essential. Research of denitrification process and balancing of dissolved oxygen is aquatic system is necessary if nitrate concentration are observed to increased unacceptable levels.

05. Water hyacinth ponds will provide nutrient removal under all conditions. Additional information is needed to establish an optimum harvesting strategy for the plants, and to improve methods for achieving phosphorous effluent standards.

06. Pollutant removal rate may be increased by raising or adjusting the sewage PH. This will provide some additional favorable condition for sewage treatment. This requires detail study.

07. Other than organic matter, nitrogen, phosphorous, and heavy metals is considered as major pollutants in sewage. The removal of these pollutants are a function of the waste waters DO/redox potential which is a consequence of the BOD/oxygen flux balance. Thus increasing the DO level in sewage, either by diffused air through mechanical aeration or by direct addition of oxygen, the removal rate of these pollutants need further study.

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APPENDIX A

Evapotranspiration and evaporation test data and results

Table A.1 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Diluted sewage.

2. Type of water hyacinth : Short stem & smaller size.

3. Weather : Sunny day.

4. Surface area : 0.0960 m^2.

5. Depth of sample column : 0.30 m.

SL No.	12 Hour Time	Evapotranspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature.°C	Remarks
1.	6AM	-	-	-	29.5	
2.	8AM	150	46	3.26	30.5	
3.	10AM	160	50	3.2	32	
4.	12NOON	175	52	3.36	33.5	
5.	2PM	160	48	3.33	34	
6.	4PM	190	54	3.51	34.5	
7.	6PM	175	50	3.5	32.5	
8.	8PM	130	46	2.82	31.5	
9.	10PM	80	37	2.16	31	
10.	6 AM	260	120	2.16	30	

Table A.2 Evapotranspiration aand Evaporation Test Data and Results.

1. Sample used : Diluted sewage.

2. Type of water hyacinth : Medium height.

3. Weather : Sunny day.

4. Surface area : 0.0960 m^2.

5. Depth of sample column : 0.30 m.

SL No.	12 Hour Time	Evapotran - spiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temper-ature.°C	
1.	6AM	-	-	-	29.5	
2.	8AM	170	46	3.7	30.5	
3.	10AM	185	50	3.7	32	
4.	12NOON	200	52	3.84	33.5	
5.	2PM	190	48	3.95	34	
6.	4PM	204	54	3.77	34.5	
7.	6PM	192	50	3.84	32.5	
8.	8PM	170	46	3.6	31.5	
9.	10PM	90	37	2.43	31	
10.	6 AM	298	120	2.4	30	

Table A.3. Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Diluted sewage.

2. Type of water hyacinth : Long stem type.

3. Weather : Sunny day.

4. Surface area : 0.0960 m^2.

5. Depth of sample column : 0.30 m

SL No.	12 Hour Time	Evapotranspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature. ^oC	
1.	6AM	-	-	-	29.5	
2.	8AM	190	46	4.13	30.5	
3.	10AM	196	46	3.92	32	
4.	12NOON	215	52	4.13	33.5	
5.	2PM	180	48	3.75	34	
6.	4PM	230	54	4.25	34.5	
7.	6PM	215	50	4.3	32.5	
8.	8PM	201	46	4.3	31.5	
9.	10PM	110	37	2.98	31	
10.	6AM	325	120	2.7	30	

Table A.4. Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Medium dense sewage.
2. Type of water hyacinth : Short stem type.
3. Weather : Sunny day.
4. Surface area : 0.0960 m^2.
5. Depth of sample column : 0.30 m.

SL No.	12 Hour Time	Evapotranspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature. °C	
1.	6AM	-	-	-	30	
2.	8AM	135	40	3.38	31	
3.	10AM	148	44	3.6	32	
4.	12NOON	160	47	3.4	34	
5.	2PM	170	50	3.4	34.5	
6.	4PM	164	45	3.6	34	
7.	6PM	150	42	3.5	33	
8.	8PM	132	35	3.7	32.5	
9.	10PM	74	32	2.31	31	
10.	6AM	240	110	2.18	30	

Table A.5 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Medium dense Sewage.
2. Type of water hyacinth : Medium height type.
3. Weather : Sunny day.
4. Surface area : 0.0960 m^2.
5. Depth of sample column : 0.30 m.

SL No.	12 Hour Time	Evapotranspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature.°C	
1.	6AM	-	-	-	30	
2.	8AM	152	40	3.8	3.1	
3.	10AM	165	44	3.75	32	
4.	12NOON	178	47	3.78	34	
5.	2PM	190	50	3.8	34.5	
6.	4PM	180	45	4.0	3.4	
7.	6PM	173	42	4.11	33	
8.	8PM	135	35	3.85	32.5	
9.	10PM	80	32	2.5	31	
10.	6AM	268	110	2.4	30	

Table A.6 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Medium dense sewage.

2. Type of water hyacinth : longer steam type.

3. Weather : Sunny day..

4. Surface area : 0.0960 m^2.

5. Depth of sample column : 0.30 m.

SL No.	12 Hour Time	Evapotranspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature. ^oC	
1.	6AM	-	-	-	30	
2.	8AM	160	40	4.0	31	
3.	10AM	168	43	3.9	32	
4.	12NOON	180	47	3.9	34	
5.	2PM	196	50	3.92	34.5	
6.	4PM	189	45	4.2	34	
7.	6PM	180	42	4.28	33	
8.	8PM	145	35	4.14	32.5	
9.	10PM	105	32	3.28	31	
10.	6AM	280	110	2.54	30	

Table A.7 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Strong sewage.

2. Type of water hyacinth : Short stem type.

3. Weather : Sunny day.

4. Surface area : 0.0960 m^2.

5. Depth of sample column :0.30 m.

SL No.	12 Hour Time	Evapotranspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature. ^oC	
1.	6AM	-	-	-	30	
2.	8AM	100	35	2.85	31	
3.	10AM	112	38	2.94	33.5	
4.	12NOON	120	42	2.85	34.5	
5.	2PM	130	45	2.88	34.5	
6.	4PM	125	43	2.9	34.5	
7.	6PM	116	40	2.9	33	
8.	8PM	102	33	3.0	32	
9.	10PM	60	30	2.1	31	
10.	6AM	195	98	2.0	29.5	

Table A.8 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Strong sewage.

2. Type of water hyacinth : Medium height type.

3. Weather : sunny day.

4. Surface area : 0.0960 m^2.

5. Depth of sample column : 0.30 m

SL No	12 Hour Time	Evapotransp-spiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature.°C	Remarks.
1.	6AM	-	-	-	30	
2.	8AM	120	36	3.33	31	
3.	10AM	130	38	3.42	33.5	
4.	12NOON	142	42	3.38	34.5	
5.	2PM	155	45	3.94	34.5	
6.	4PM	148	43	3.44	34.5	
7.	6PM	130	40	3.25	33	
8.	8PM	110	33	3.3	32	
9.	10PM	72	30	2.4	31	
10.	6AM	230	98	2.35	29.5	Nextday

Table A.9 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Strong sewage.
2. Type of water hyacinth : Longer stem type
3. Weather : Sunny day.
4. Surface area : 0.0960 m^2.
5. Depth of sample column : 0.30 m.

SL No.	12 Hour Time	Evapotransp-spiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature. ^oC	Remarks.
1.	6AM	-	-	-	30	
2.	8AM	140	35	4.0	31	
3.	10AM	142	38	3.73	33.5	
4.	12NOON	155	42	3.69	34.5	
5.	2PM	170	45	3.77	34.5	
6.	4PM	160	43	3.7	34.5	
7.	6PM	147	40	3.67	33	
8.	8PM	115	33	3.48	32	
9.	10PM	80	30	2.7	31	
10	6AM	245	98	2.5	30	

Table A.10 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Diluted sewage.
2. Type of water hyacinth : Longer stem type.
3. Weather : Sunny day.
4. Surface area : 0.3780 m^2.
5. Depth of sample column : 0.34 m.

SL No.	12 Hour Time	Evapotranspspiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature.^oC	Remarks.
1.	6AM	-	-	-	30	
2.	8AM	660	165	4.0	30.0	
3.	10AM	690	180	3.83	30.5	
4.	12NOON	750	190	3.95	32.5	
5.	2PM	840	200	4.2	34	
6.	4PM	800	195	4.1	34.5	
7.	6PM	750	180	4.1	33	
8.	8PM	700	170	4.1	32.5	
9.	10PM	380	140	2.7	32	
10.	6AM	1130	450	2.5	30	Nextday

Table A.11 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Diluted sewage.

2. Type of water hyacinth : Longer stem type.

3. Weather : Sunny day.

4. Surface area : 0.3780 m^2.

5. Depth of sewage column : 0.17 m.

SL No.	12 Hour Time	Evapotransp-spiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature.^oC	Remarks.
1.	6AM	-	-	-	30	
2.	8AM	640	190	3.36	30.5	
3.	10AM	665	205	3.24	32	
4.	12NOON	720	225	3.2	32.5	
5.	2PM	815	240	3.3	34	
6.	4PM	775	225	3.4	34.5	
7.	6PM	720	190	3.7	33	
8.	8PM	680	176	3.86	32.5	
9.	10PM	370	135	2.74	32	
10	6AM	1100	435	2.5	30	

Table A.12 Evapotranspiration and Evaporation Test Data and Results.

1. Sample used : Diluted sewage.

2. Type of water hyacinth : Longer stem type.

3. Weather : Sunny day.

4. Surface area : 0.3780 m^2.

5. Depth of sewage column : 0.34 m.

SL No.	12 Hour Time	Evapotransp-Spiration (ml) E_t	Evaporation (ml) E_p	Ratio E_t/E_p	Temperature.°C	Remarks.
1.	6AM	-	-	-	30	
2.	8AM	350	165	2.12	30	
3.	10AM	375	180	2.08	31	
4.	12NOON	405	190	2.13	32.5	
5.	2PM	440	200	2.2	33	
6.	4PM	430	195	2.2	33.5	
7.	6PM	410	180	2.2	33	
8.	8PM	340	170	2.3	32.5	
9.	10PM	180	140	7.29	32	
10	6AM	575	450	1.3	30	

APPENDIX B

Pollutants removal test data and results

Table B.1 : BOD Removal in batch culture (with water hyacinth).

Depth of Sewage column: 0.30m.

Type of Sewage sample: Prepared.

Average day temparature: 30^0C

Sample Character-istics	Before Treat-ment	After Treatment in days (mg/L)						Removal (%)
		1	2	3	4	5	6	
Rawsewage	185	92	76	66	64	-	-	64.8
S= 90% W = 10%	180	90	74	65	64	-	-	64
S = 80% W =20%	160	85	72	61	56	51	50	68.6
S = 65% W = 35%	110	60	48	38	35	33	30	72.7
S = 50% W = 50%	100	58	47	38	33	29	26	74
S = 40% W = 60%	75	45	32	26	22	20	19	74.6
S =25% W = 75%	70	42	28	24	21	19	17	75.7

* S = Sewage sample.

W = Water added.

BOD Values represent organic loading.

Table B.2: COD Removal in batch culture (with water hyacinth).

Depth of Sewage column: 0.30m.

Type of Sewage sample: Prepared.

Average day temperature: 30^0C

Sample Characteristics	Before Treatment	After Treatment in days (mg/L)						Removal (%)
		1	2	3	4	5	6	
Rawsewage	410	205	170	155	145	-	-	65
S= 90% W = 10%	390	200	170	155	145	-	-	65
S = 80% W =20%	320	170	140	120	110	105	105-	68
S = 65% W = 35%	195	110	90	75	65	58	52	73
S = 50% W = 50%	170	100	82	68	58	50	45	73.5
S = 40% W = 60%	160	95	82	68	56	46	40	75
S =25% W = 75%	145	90	75	63	53	43	35	76

* S = Sewage sample.

W = Water added.

COD Values represent organic loading.

Table B.3 : BOD Removal in batch culture (with out water hyacinth).

Depth of Sewage column: 0.30m.

Type of Sewage sample: Prepared.

Average day temparature: 30^0C

Sample Character-istics	Before Treat-ment	After Treatment in days (mg/L)						Removal (%)
		1	2	3	4	5	6	
Rawsewage	185	100	93	88	84	81	79	58
S= 90% W = 10%	180	100	92	86	81	78	75	58
S = 80% W =20%	160	90	83	77	72	68	65	59.5
S = 65% W = 35%	110	70	62	56	51	47	43	61
S = 50% W = 50%	100	65	58	52	47	43	40	60
S = 40% W = 60%	75	50	42	36	32	30	28	62.2
S =25% W = 75%	70	45	38	34	31	29	26	63

* S = Sewage sample.

W = Water added.

BOD Values represent BOD_5

Table B.4 : COD Removal in batch culture (with out water hyacinth).

Depth of Sewage column: 0.30m.

Type of Sewage sample: Prepared.

Average day temparature: 30^0 C

Sample Character- istics	Before Treat- ment	After Treatment in days (mg/L)						Removal (%)
		1	2	3	4	5	6	
Rawsewage	410	225	205	190	180	175	170	58.5
S= 90% W = 10%	390	220	200	184	172	166	160	59
S = 80% W =20%	320	185	165	150	140	135	130	59.5
S = 65% W = 35%	195	120	105	96	88	80	75	61.5
S = 50% W = 50%	170	105	92	83	76	70	65	61.75
S = 40% W = 60%	160	100	86	78	72	66	60	62.5
S =25% W = 75%	145	95	82	72	64	58	53	63.5

* S = Sewage sample.

W = Water added.

BOD Values represent BOD_5

Table B.5: Removal of organic matter in batch culture with water hyacinth.

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Average day temperature: 30^0C

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted **BOD_5
0	100	-	-	33	
1	58	42	42	32	49
2	48	10	17.2	33	40
3	40	8	16.6	32.5	34
4	34	6	15	32	29
5	31	5	14.7	33	26
6	25	4	12.9	32	21
7					
Total	100	75	75		

* Average day temperature.

* BOD or COD value represents organic loading in sewage.

** Actual BOD_5 where Evapotranspiration effect has been considered.

Table B.6 : Removal of organic matter in batch culture (with out water hyacinth).

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted **BOD_5
0	100	-	-	33	First day
1	62	38	38	32	57
2	53	9	14.5	33	48
3	46	7	13	32.5	42
4	40	6	13	32	33
5	36	4	10	33	30
6	34	2	6	32	28
7					
Total	100	64	64		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual BOD_5 where Evaporation effect has been considered.

Table B.7 : Removal of organic matter in batch culture (with water hyacinth).

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature 0C	Adjusted **COD
0	190	-	-	33	First day
1	105	85	44.7	32	89
2	85	20	19	33	71
3	69	16	18	32.5	58
4	59	10	14.5	32	49
5	54	5	8.5	33	45
6	50	4	7.4	32	42
7					
Total	190	140	73.6		

* Average day temperature.

** Actual COD where Evaporation effect has been considered.

Table B.8 : Removal of organic matter in batch culture (with out water hyacinth).

Depth of Sewage column: 0.50m.

Type of Sewage sample: Low concentrated.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature °C	Adjusted **COD
0	190	-	-	33	First day
1	114	76	40	32	104
2	100	14	12.2	33	91
3	90	10	10	32.5	82
4	82	8	8.8	32	75
5	76	6	7.3	33	69
6	72	4	5.2	32	65
7					
Total	190	118	62		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual COD where Evaporation effect has been considered.

Table B.9 Hourly COD removal in batch culture.

Depth of sewage : 0.34 m

SL NO.	Time	Use of w.H COD (mg/L)	Without W.H COD (mg/L)	Temperature ^0C	Remarks
1.	6AM	410	410	27.5	
2.	8AM	370	380	28	
3.	10AM	320	350	28.5	
4.	11AM	320	335	28.5	
5.	12NOON	305	320	29	
6.	1PM	290	310	29	
7.	2PM	280	300	29.5	
8.	3PM	270	292	29	
9.	4PM	262	281	29	
10.	5PM	254	284	29	
11.	6PM	246	278	28	
Total		164(40%)	132(32%)		

* W H = Water Hyacinth.

Table B.10 : Removal of organic matter in flowing condition (with water hyacinth).

Depth of Sewage column: 0.34 m.

Type of Sewage sample: Medium dense.

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted **BOD_5
0	170	-	-	33	First day
1	76	94	55	34	64
2	60	16	21	33.5	50
3	54	6	10	32.5	45
4	50	4	7.4	34	42
5	47	3	6	34.5	39
6	45	2	4.2	33	37
7					
Total	170	125	73.5		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual BOD_5 where Evapotranspiration effect has been considered.

Table B.11 : Removal of organic matter in flowing condition (with water hyacinth).

Depth of Sewage column: 0.34 m.

Type of Sewage sample: Medium dense.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature °C	Adjusted **COD
0	380	-	-	33	First day
1	170	210	55.2	34	142
2	140	30	17.6	33.5	117
3	125	15	10.7	32.5	104
4	115	10	8	34	96
5	109	6	5.2	34.5	91
6	105	4	3.6	33	88
7					
Total	380	275	72.3		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual COD where Evaporation effect has been considered.

Table B.12 : Removal of organic matter in flowing condition (with out water hyacinth).

Depth of Sewage column: 0.34 m.

Type of Sewage sample: Medium dense.

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted **BOD_5
0	180	-	-	32.5	First day
1	106	74	41.1	32	97
2	96	10	9.4	33	87
3	89	7	7.3	33.5	81
4	84	5	5.6	32	76
5	80	4	4.7	34	73
6	78	2	2.5	32.5	71
7					
Total	180	102	56.67		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual BOD_5 where Evapotranspiration effect has been considered.

Table B.13 : Removal of organic matter in flowing condition (with out water hyacinth).

Depth of Sewage column: 0.34 m.

Type of Sewage sample: Medium dense.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature ^0C	Adjusted **COD
0	400	-	-	32.5	First day
1	230	170	42.5	32	209
2	207	23	10	33	188
3	190	17	8.2	33.5	173
4	178	12	6.3	32	162
5	170	8	4.5	34	155
6	165	5	3.0	32.5	150
7					
Total	400	235	58.75		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual COD where Evaporation effect has been considered.

Table B.14 : Removal of organic matter in flowing condition (with water hyacinth).

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted **BOD_5
0	70		--	33	First day
1	34	36	51.4	34	28.5
2	26	8	23.5	32.5	22
3	20	6	23.3	33	16.5
4	16	4	20	33	13.5
5	13	3	18.75	32	11
6	11	2	15.4	32.5	9
7					
Total	70	59	84.2		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual BOD_5 where Evapotranspiration effect has been considered.

Table B.15 : Removal of organic matter in flowing condition (with out water hyacinth).

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted $**BOD_5$
0	80	-	-	32	First day
1	54	26	32.5	33	45
2	46	8	14.8	32.5	38.5
3	40	6	13	33	33.5
4	36	4	10	33	30
5	33	3	8.3	32	27.5
6	30	3	9.0	33.5	25
7					
Total	80	50	62.5		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual BOD_5 where Evapotranspiration effect has been considered.

Table B.16 : Removal of organic matter in flowing condition (with water hyacinth).

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature ^0C	Adjusted **COD
0	160	-	-	33	First day
1	80	80	50	34	66
2	58	22	27.5	32.5	49
3	46	12	20.6	33	38.5
4	38	8	17.14	33	30
5	32	6	15.8	32	25
6	28	4	12.5	32.5	22
7		-			
Total	160	132	82.5		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual COD where Evaporation effect has been considered.

Table B.17: Removal of organic matter in flowing condition (with out water hyacinth).

Depth of Sewage column: 0.50 m.

Type of Sewage sample: Low concentrated.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature 0C	Adjusted **COD
0	175	-	-	32	First day
1	120	55	31.4	33	109
2	105	15	12.5	32.5	95
3	95	10	10.5	33	79
4	89	6	6.3	33	74
5	84	5	5.6	32	68
6	80	4	4.75	33.5	64
7					
Total	175	95	58.2		

* Average day temperature.

* BOD/COD value represents organic loading in sewage.

** Actual COD where Evaporation effect has been considered.

Table B.18 : Removal of organic matter in flowing condition (with water hyacinth).

Depth of Sewage column: 0.17 m.

Type of Sewage sample: Low concentrated.

Treatment in days	BOD_5 mg/L	BOD_5 Removal	% Removal	*Temperature ^0C	Adjusted $**BOD_5$
0	60	-	-	33	First day
1	34	26	43.3	32	29
2	24	10	29.4	34	20
3	18	6	25	32.5	15
4	13	5	27.2	32	11
5	9	4	30	33.5	7
6	6	3	33	32	5
7					
Total	60	54	90		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual BOD_5 where Evapotranspiration effect has been considered.

Table B.19: Removal of organic matter in flowing condition (with water hyacinth).

Depth of Sewage column:0.17 m.

Type of Sewage sample: Low concentrated.

Treatment in days	COD mg/L	COD Removal	% Removal	*Temperature 0C	Adjusted **COD
0	130	-	-	33	First day
1	75	55	42.3	32	62.5
2	50	25	26.67	34	41
3	35	15	30	32.5	29
4	25	10	28.5	32	21
5	20	5	20	33.5	16
6	15	5	25	32	11
7					
Total	130	115	88.5		

* Average day temperature.

* BOD and COD value represents organic loading in sewage.

** Actual COD where Evaporation effect has been considered.

Table B.20 Hourly COD removal in flowing condition.

Depth of sewage: 0.34m.

SL NO.	Time	Use of w.H COD (mg/L)	Without W.H COD (mg/L)	Temperature ^0C	Remarks
1.	6AM	160	175	30.5	
2.	8AM	140	163	32	
3.	10AM	126	154	32.5	
4.	11AM	120	150	33	
5.	12NOON	114	146	33	
6.	1PM	108	143	33.5	
7.	2PM	103	140	34	
8.	3PM	98	138	34	
9.	4PM	94	136	34.5	
10.	5PM	91	134	33	
11.	6PM	88	133	32.5	
Total		45%	24%		

* W H = Water Hyacinth.

Table: B.21 Nitrogen Removal in Pond System (With water hyacinth).

Treatment (days)	Total-N mg/l	Removal mg/l	% Removal
0	15.00	-	-
1	10.50	4.50	30
2	8.50	6.50	43.30
3	7.25	7.75	51.67
4	6.25	8.75	58.33
5	5.75	9.25	61.66
6	5.25	9.25	65.00

Table B.22 Nitrogen Removal in Pond System (without water hyacinth)

Treatment (days)	Total-N mg/l	Removal mg/l	% Removal
0	15.00	-	-
1	13.00	2.00	13.33
2	12.00	3.00	20.00
3	11.25	3.75	25.00
4	10.75	4.25	28.33
5	10.25	4.75	31.66
6	9.75	5.25	35.00

Table: B.23 Phosphorus Removal in Pond System (with water hyacinth)

Treatment (days)	Phosphorus mg/l	Removal mg/l	% Removal
0	3.50	-	-
1	2.80	0.70	20.00
2	2.4	1.10	31.40
3	2.10	1.40	40.00
4	1.90	1.60	45.70
5	1.70	1.80	51.40
6	1.50	2.00	53.0

Table: B.24 Phosphorus Removal in Pond System (without water hyacinth)

Treatment (days)	Phosphorus mg/l	Removal mg/l	% Removal
0	3.50	-	-
1	2.20	0.30	8.60
2	3.00	0.50	14.30
3	2.80	0.70	20.00
4	2.70	0.80	22.80
5	2.60	0.90	25.70
6	2.50	1.00	28.50

Table B.25 Suspended Solids and Turbidity Removal in Pond System (with water hyacinth)

Treatment (days)	Turbidity contents (NTU)	Turbdity Removal %	SS (mg/l)	SS Removals %
0	225	-	180	-
1	125	44.44	120	33.3
2	110	51.10	74	59
3	100	55.50	55	69.4
4	92	59.10	40	77.7
5	86	61.70	28	84.4
6	81	64.00	20	89

Table B.26 Suspended Solids Removal in Pond System (without water hyacinth)

Treatment days	Turbidity (NTU)	Removal %	SS (mgl)	Removal
0	225	-	180	-
1	175	22.2	150	16.6
2	160	31.1	130	27.7
3	150	33.3	120	33.3
4	140	37.7	112	37.7
5	135	40	106	41.1
6	130	42.2	102	43