A

DISSERTATION

ON

BIOLOGICAL NUTRIENT REMOVAL FROM WASTEWATER BY USING SINGLE SBR AND WATER HYACINTH

Submitted in partial fulfillment of the requirements for the award of the degree

Of

MASTER OF TECHNOLOGY
IN
PULP AND PAPER TECHNOLOGY

Submitted by

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JUNE-2010

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this Dissertation report entitled **"Biological nutrient removal from wastewater by using single SBR and water hyacinth"** submitted for partial fulfillment of the requirements for the award of the degree Master of Technology (Pulp & Paper) at IIT Roorkee, is an authentic record of my own work carried out under the supervision of **Dr. M. C. Bansal**, Professor & **Dr. U. K. Ghosh**, Assistant Professor Department of Paper Technology, IIT Roorkee, Saharanpur Campus, Saharanpur.

The matter embodied in this Dissertation has not been submitted by me for the award of any other degree of this or in any other Institute.

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Date: 30/06/2010

Place: Saharanpur

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ACKNOWLEDGEMENT

I am highly indebted to my guides Dr. M. C. Bansal, Professor and Dr. U. K. Ghosh, Assistant Professor, IIT Roorkee, Department of Paper Technology, Saharanpur Campus, for inspiring me to enhance my knowledge by pursuing the innovative and challenging area of my dissertation **"Biological nutrient removal from wastewater by using single SBR and water hyacinth".** Their skillful guidance has helped me to logically interpret the experimental results of this study.

I also express my gratitude to Mr. Rakesh Kumar Arora [Technical Suptd.], Chemistry lab for his precious support to help me for completion of this dissertation.

I would like to express to my special thanks to Mr. Surendra P. Singh, Mr. Asutosh Kumar and Mr. Parveen Kumar, Research Scholars at DPT, IIT Roorkee for their kind support and all the favors towards me.

I express my sincere thanks to all the persons who have helped me during the work.

I am highly obliged to the **Almighty God** for his wonderful care towards me.

Finally, and most importantly, I thank my family members for their encouragement and patience.

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ABSTRACT

Nowadays, environmental legislation has become more restricted in the nutrient wastewater discharge, especially in the sensitive areas and vulnerable zones. Wastewater treatment technology is posing serious techno-economic problems in cities, particularly in developing countries. So, many studies have been stimulated on the understanding, developing and improving the biological nutrient removal processes.

In this dissertation work, the two different methods of treatment have been studied for Saharanpur municipal wastewater.

(1) Single Sequencing Batch Reactor (SBR) Process.

(2) Purification by water hyacinth (*Eichhornia crassipes*).

- In the SBRs process, aeration was provided by diffused air devices which have the added advantage as mixers or aerators. In this process aerobic digestion by bacteria occurs in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. This technology used though appears to be simple yet still achieves a high degree of Biological Nutrient Removal (BNR). The process used in laboratory is a single tank Sequencing Batch Reactor (SBR). The results from the laboratory work are excellent but have to be confirmed in the pilot plant studies. It was found that a certain degree of anaerobic pretreatment can reduce part of the carbon concentration most efficiently while still leaving sufficient Chemical Oxygen Demand (COD) required for successful BNR. Medium-to-low strength wastewater has been supplied in SBR. This was operated with different FILLING/REACTION time ratios.

During **Filling**, fermentation reactions probably occurred and this resulted in up to 86% reduction of the initial dissolved BOD_5 concentration. Degradation of waste then continued into the **Reaction** period. This preliminary assessment showed that the SBR is, potentially, a viable option for wastewater treatment, especially since the aeration time required for treatment to achieve the effluent quality is small.

The SBR was operated for 4 months for treating the "Municipal wastewater". In order to have a mixed culture, the system should be able to perform carbon oxidation, nitrification, de-nitrification and biological phosphorus removal. Despite high influent concentrations of approximately 58.40 mg L^{-1} N and 4.56 mg L^{-1} total P, good effluent quality of less than 1 mg L^{-1} N and less than 1 mg L^{-1} total P and high removal of BOD, COD, and TSS in the range of 94.57, 92.12, and 88.34% has been achieved. Furthermore the operation of the small SBR systems has proved to be simple and reliable.

- Wastewater purification by water-hyacinth (*Eichhornia crassipes*), is a relatively new possible solution. This floating plant has been used in aquatic systems for wastewater purification for many years worldwide. A lot of interests have been shown for this plant in last few years in India (Aoi T. *et al.*, 1996). In this study the suitability and effectiveness of water-hyacinth in treating Municipal wastewater has been analyzed. A 28-days experiment was performed in natural conditions. Several parameters were measured and analyzed, including the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammonia and phosphate contents, pH value, DO and turbidity. Laboratory analyses indicated that the water-hyacinth culture drastically reduced the BOD from 101.67 to 31.71 mg L^{-1}, COD was reduced from 505 to 264.08 mg L^{-1} and pH value fell slightly from 7.19 to 6.87. Results obtained from our studies and other papers in using water hyacinth and aquatic systems have been analyzed. These studies and scientific papers also describe this plant as notorious weed and propose different control measures. The final effluent from water-hyacinth could be used for irrigation and recycled to a flowing stream for other uses except for drinking purposes.

Keywords:- Biological Nutrient Removal (BNR), De-nitrification, Nitrification, Phosphorus removal, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Sequencing Batch Reactor (SBR), Municipal wastewater, Water hyacinths, *Eichhornia crassipes*, Notorious weed.

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ABBREVIATIONS

AOB: - Ammonia Oxidizing Bacteria

BNR: - Biological Nutrient Removal

BOD: - Biochemical Oxygen demand

COD: - Chemical Oxygen demand

DNR: - Dissimilating nitrate reduction

DO: - Dissolved oxygen

EBPR:-Enhanced Biological Phosphorus Removal

F/M: - Food to microorganism

FA: - Free ammonia

VFA: - Volatile fatty acids

GAOs: - Glycogen Accumulation Organisms

HRT: - Hydraulic retention time

NOB: - Nitrite Oxidizer Bacteria

NTU: - Nephelometric Turbidity Units

PAOs: - Phosphorus accumulation organism

PHA: - Polyhydroxyalkanoates

RPM: - Revaluation per minute

SBR: - Sequencing batch reactor

SRT: - Solids retention time; Sludge age

TSS: - Total suspended solids

CHAPTER-1

Single Sequencing Batch Reactor (SBR) Process

1.1 SUMMARY

SBR technology is not new. In fact, it precedes the use of continuous flow activated sludge technology. The precursor to this was a fill-and-draw operated on batch, similar to the SBR. Between 1914 and 1920, many difficulties were associated with operating these fill-and-draw systems, most resulting from the process valving required to switch flow from one reactor to another, operator attention required. Interest in SBR was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems.

The Sequencing Batch Reactor (SBR) is a fill-and-draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single reactor which operates in a batch treatment mode to remove undesirable component, and subsequently discharged as repeating a cycle (sequence) continuously. All the operations (fill, react, settle and draw) are achieved in a single reactor. SBR can be designed and operated to enhance removal of Nitrate, phosphorus, and ammonia, in addition to removing TSS and BOD and it also attains nutrient control without the addition of chemical.

1.2 INTRODUCTION

The reactor is the principal component of the SBR system, as all of the biological treatment steps take place in one tank. In contrast to conventional continuous flow treatment process, the SBR system operates on a time basis rather than on volume basis. The individual process phases add to make a treatment cycle. The length of each cycle is dependent on the characteristics of the waste water and the desired discharge. A normal cycle lasts up to 8 hours, giving up to three cycles per day.

The experience gained over the years of operation of biological sewage treatment plants on different types of effluents and the process evaluation of these systems has given rise to a greater understanding of the biological nutrient removal process. Consequently this has led to improved methods of waste water treatment. SBR technology is the state of the art process available today. The control method available today has optimized the performance of SBR technology, so that it far exceeds conventional treatment concepts.

1.2.1 Sequencing Batch Reactor (SBR) Process Description

The Sequencing Batch Reactor (SBR) is the name given to a wastewater treatment system based on activated sludge and operated in a fill-and-draw cycle. The most important difference between SBR and the conventional activated sludge systems is that the reaction and settling takes place in the same reactor. Basically, the **sequencing batch reactor (SBR) process is a sequential suspended growth (activated sludge) process in which all the major steps occur in the same tank in sequential order (figure 1)**

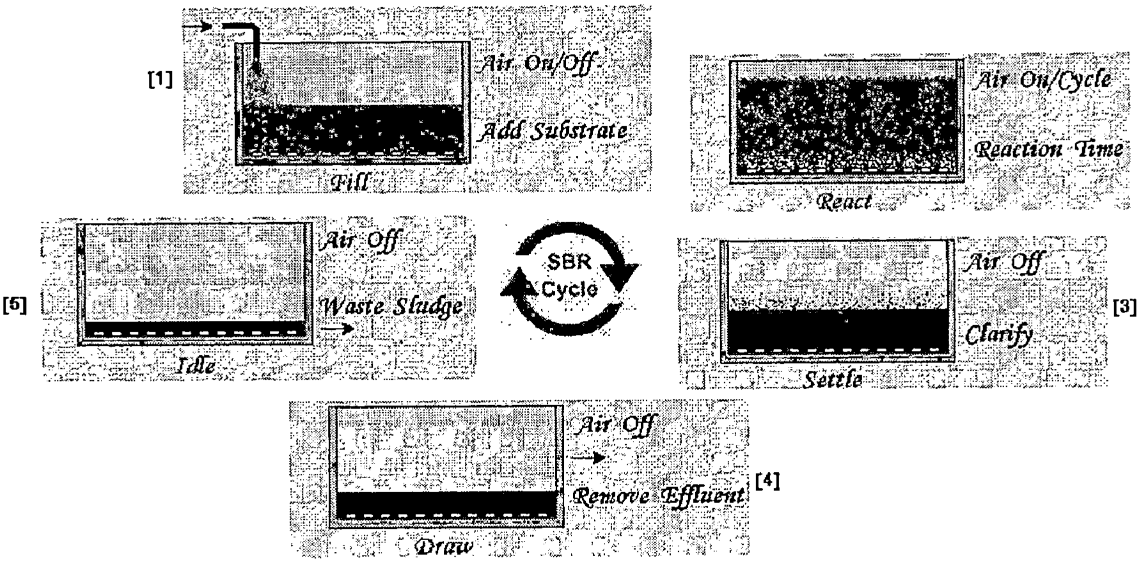

Figure 1: Typical sequence operation in SBR

1. **Fill**: Raw wastewater flows into the reactor and mixes with the biomass held in the tank.
2. **React**: The biomass consumes the substrate under controlled conditions: anaerobic, anoxic or aerobic reaction depending on the kind of treatment applied.
3. **Settle**: Mixing and aeration are stopped and the biomass is allowed to separate from the liquid, resulting in a clarified supernatant.
4. **Draw**: Supernatant or treated effluent is removed.
5. **Idle**: This is the time between cycles. Idle is used in a multi tank system to adjust cycle time between SBR reactors because idle is not a necessary phase, it is sometimes omitted. In addition, sludge wasting can occur during this phase.

The Sequencing Batch Reactor (SBR) is an activated sludge process designed to operate under non-steady state conditions. The conditions applied during the fill and react phases must be adjusted according to the treatment objectives (organic matter, nitrogen or phosphorus removal) (Fabregas *et al.*, 2004).

As mentioned before, during the **fill phase,** the wastewater enters the reactor. The main effect of the fill phase, however, is to determine the hydraulic characteristics of the bioreactor. The kind of fill strategy applied depends upon a variety of factors, including the nature of the facility and the treatment objectives.

When focusing on the length of the fill phase both short and long fill phases are found. If the fill is short, the process will be characterized by a high instantaneous process loading factor, thereby making it analogous to a continuous system with a tanks-in-series configuration. In that case, the biomass will be exposed initially to a high concentration of organic matter and other wastewater constituents, but the concentration will drop over time. Conversely, if the fill phase is long, the instantaneous process loading factor will be small and the system will be similar to a completely mixed continuous flow system in its performance. This means that the biomass will experience only low and relatively constant concentrations of the wastewater constituents. The long fill can be applied during the whole operational time becoming a continuous fill phase (Grady, 1999).

Others strategies of filling can be applied such as a focus on the number of filling events. The classical operation of SBR is executing a sole filling event during a cycle, but more than one filling event (two, three.....) mainly in nutrient removal and getting, in some cases, a continuous filling.

At the same time, three variations of the fill phase can also be applied depending on the strategy: static fill, mixed fill and aerated fill. If the fill phase is static, influent wastewater is added to the biomass already present in the reactor. Static fill is characterized by no mixing or aeration, meaning that there will be a high substrate (food) concentration when mixing begins. A high food to microorganisms (F/M) ratio creates an environment favourable to flock forming organisms versus filamentous organisms (EPA, 1999), which provides good settling characteristics for the sludge. Additionally, static fill conditions favour organism that produce internal storage products during high substrate conditions, a requirement for biological phosphorus removal. Static fill may be compared to using "selector" compartments in a conventional activated sludge system to control the F/M ratio. If the fill phase is mixed, the influent is mixed with the biomass, which then initiates biological reactions. During mixed fill, bacteria biologically degrade the organics and use residual oxygen or alternative electron acceptors, such as nitrate. In this environment, de-nitrification can occur under these anoxic conditions. In the conventional biological nutrient removal activated sludge system, mixed fill is comparable to the anoxic zone which is used in de-nitrification. Anaerobic conditions can also be achieved during the mixed fill phase. After the microorganisms use the nitrate, sulphate becomes the electron acceptor. Anaerobic conditions are characterized by the lack of oxygen and sulphate as the electron acceptor (EPA, 1999).

During the **react phase**, the biomass is allowed to act upon the wastewater constituents. The biological reactions (the biomass growth and substrate utilization), initiated in the fill phase, are completed in the react phase, in which anaerobic, anoxic or aerobic mix phases are available. So the fill phase should be thought of as a "fill plus react" phase with react continuing after the fill has ended. As a certain total react period will be required to achieve the process objectives, if the fill period is short, the separate react period will be long, whereas if the fill period is long the separate react period will be short to nonexistent. The two periods are usually specified separately because of the impact that each one has on the performance of the system.

During **aerobic reaction phase**, the aerobic reactions initialized during the aerobic fill are completed and nitrification can be achieved. If the anoxic reaction is applied, de-nitrification can be attained and in the anaerobic reaction phase, phosphorus removal can be achieved.

All these facts reflect one of the main advantages of the batch reactors, namely flexibility. SBRs are especially preferred when nutrient removal is important, because enrichment in nitrifiers, de-nitrifiers and phosphorus removal bacteria may take place in the same vessel by simply changing the mixing and aeration conditions and time schedules. (EPA, 1999; Irvine *et al.* 1997; Wilderer *et al.* 2001)

- The operational flexibility of an SBR allows the control of **filamentous bacteria** through cycles. A high substrate may be imposed by a static fill operation and the react phase may be followed by an extended phase of starvation which, in turn, promotes the enrichment of flock-forming bacteria and the accumulation of exopolymers.
- The SBR system provides the flexibility needed to treat a **variable wastewater** (Load and composition) by simply adjusting the cycle time (e.g. using the time set aside for the idle phase).
- The ability to hold contaminants until they have been completely degraded makes the system excellent for the treatment of **hazardous compounds**.
- The concentration of biomass in the stream leaving the system can be kept low by **minimising turbulence** during the settle phase.
- The settle phase can be extended to increase **sludge thickening** thus decreasing water content in the wasted sludge.
- The capacity to adjust the energy input and the fraction of volume used according to the influent loading can result in a **reduction in operational costs.** In addition, less space is required as all operations occur in one basin.

1.2.2 Operating Characteristics of SBR Process

The SBRs are operated in three cycles per day. A cycle is a group of operations or phases compromising between the beginning (fill) and the end (draw or idle) of a waste water treatment. These cycles are defined by five phases: **fill, react, settle, draw** and **idle**. The total cycle time (T_c) is the sum of all these phases as given in equation 1. Sometimes idle phase is not necessary and it is omitted.

$$T_c = T_F + T_R + T_S + T_D + T_I \quad (1)$$

Where: T_c: total cycle time, h

T_F: fill time, h

T_R: react time, h

T_S: settling time, h

T_D: draw time, h

T_I: idle time, h

React time: Depending on capacity (maximum 4 hrs)

Settling time: Normally 3 hrs

Draw time: 1hr

Furthermore, the conditions applied during the react phase can be different depending on the performance desired (organic matter, nitrogen or phosphorus removal). So, aerobic, anoxic or anaerobic reaction time can be found in the react time equation 2.

Hence: $T_R = T_{AE} + T_{AX} + T_{AN}$ (2)

Where: T_{AN}: anaerobic react time, h

T_{AX}: anoxic react time, h

T_{AE}: aerobic react time, h

Also, it is important to note that a cycle has a different **effective time** to different than total cycle time. This fact is a consequence of the inoperative phase or physic operation such as settle (solid-liquid separation) and draw (decent), where no biological conversion is assumed to occur. The **effective time** (T_E) can be defined as equation 3.

$$T_E = T_C - (T_S + T_D + T_I) \quad (3)$$

Where: T_C: total cycle time, h

T_S: settle time, h

T_D: draw time, h

T_I: idle time, h

The number of cycles (N_C) per day is determined through the total cycle time (T_C), as is shown in equation 4:

$$N_C = 24 / T_C \quad (4)$$

Where: N_C: number of cycle per day

T_C: total cycle time, h

Throughout the cycle, as SBR can operate with different volume due to the filling and draw phases. Then, **total reactor volume** (V_T) can be defined as the maximum working volume and the **filling volume** (V_F) as the volume of wastewater filled and discharged every cycle. The difference between filling volume and total reactor volume in the **minimum volume** (V_{MN}) equation 5, i.e. volume that always remains inside the reactor.

$$V_{MN} = V_T - V_F \quad (5)$$

Where: V_T: total reactor volume or working volume, L

V_{MN}: minimum volume, L

V_F: filling volume, L

The definition of hydraulic retention time (HRT) for an SBR is based on the equation 6 of the continuous systems.

$$HRT = V_T/Q \quad (6)$$

Where: HRT: hydraulic retention time, d

Q: daily waste water flow rate, L/d

The flow (Q) in an SBR is defined by the product of filling volume (V_F) and number of cycles per day (N_C), equation 7.

$$Q= V_F*N_C \quad (7)$$

Where: V_F: filling volume, L

N_C: number of cycles per day

By combining equation 6 and 7, the HRT can be expressed as equation 8.

$$HRT= T_C/ (V_F/V_T)*1/24 \quad (8)$$

Where: T_C: total cycle time, h

V_F/V_T: exchange ratio

1.3 LITERATURE SURVEY

The experienced gained over the years of operation of biological sewage treatment plants on different types of influent and the process evaluation of these systems and technical components has given rise to a greater understanding of the biological decomposition process. Consequently this has led to improved methods of waste water treatment (Bernardes *et al.*, 1996).

The varying microorganisms such as **bacteria, multi-cell minute organisms, worms** etc require different conditions in order to carry out their dedicated purification tasks efficiently. In order to obtain the most efficient treatment system the requirements for the varying microorganisms must be met (Baikun *et al.*, 2007). The SBR system provides the varying environmental conditions required for each microorganism within the different phases i.e. **Aerobic, anoxic and anaerobic**. These processes are temporarily combined to produce optimal performance. SBR batch processing favours the decomposition process through alternation of anaerobic, aerobic and anoxic operating conditions (Woolard *et al.*, 2004).

1.3.1Biological Nutrient Removal

Biological nitrogen removal is used in wastewater treatment when there are concerns regarding eutrophication, when either groundwater must be protected against elevated nitrate ($N\text{-}NO3^-$) concentrations [Arnold *et al.*, 2004] or when wastewater treatment plant effluent is used for groundwater recharge or other claimed water applications. Biological nitrogen removal can be accomplished in a two stage treatment: aerobic nitrification and anoxic de-nitrification (EPA 1993).

I. Nitrification

Nitrification is the term used to describe the two steps biological process in which ammonia ($N\text{-}NH_4^+$) is oxidized to nitrite ($N\text{-}NO_2^-$) and nitrite is oxidized to nitrate ($N\text{-}NO_3^-$), under aerobic conditions and using oxygen as the electron acceptor (Van Dongen *et al.*, 2001). The need for nitrification in wastewater treatment arises from water quality concerns over the effect of ammonia on receiving water with respect to DO concentration and fish toxicity (U. Albeling *et al.*, 1992, G. Ruiz *et al.*, 2003) from the need to provide nitrogen removal to control the eutrophication, and in the control for water-reuse applications including groundwater recharge (Metcalf and Eddy, 2003).

Aerobic autotrophic bacteria are responsible for nitrification in activated sludge and bio film processes. Nitrification, as noted above, is a two-step process involving two groups of bacteria. In the first stage, ammonia is oxidized to nitrite (equation-9) by one group of autotrophic bacteria called Nitroso-bacteria or Ammonia Oxidizing Bacteria (AOB) (Ruiz *et al.*, 2003, W. Bae *et al.*, 2001). In the second stage, nitrite is oxidized to nitrate (equation-10) by another group of autotrophic bacteria called Nitro- bacteria or Nitrite Oxidizer Bacteria (NOB) (Kuba *et al.*, 1996). It should be noted that the two groups of autotrophic bacteria are distinctly different.

$$NH_4^+ + 3/2O_2 \longrightarrow NO_2^- + H_2O + 2H^+ \quad (9)$$

$$NO_2^- + 1/2O_2 \longrightarrow NO_3^- \quad (10)$$

Therefore, total oxidation reaction is desired as equation 11:

$$NH_4^+ + 2HCO_3^- + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O \quad (11)$$

as a simple word- Nitrification is the conversion of ammonia (NH_3) to nitrate (NO_3) (Jetten et al., 1999). This is a two step process in the presence of oxygen and two types of nitrifying bacteria, Nitrosomonas and Nitrobacter.

- [Ammonia (NH_3) + Oxygen (O_2) + Alkalinity + Nitrosomonas = Nitrite (NO_2)]
- [Nitrate (NO_2) + Oxygen (O_2) + Alkalinity + Nitrobacter = Nitrate (NO_3)]

In the above equation, total conversion of ammonia to nitrate takes 4.6 parts oxygen and 7.1 parts alkalinity to convert 1 part ammonia (Metcalf and Eddy, 2003).

II. De-nitrification

The biological reduction of nitrate to nitric oxide, nitrous oxide, and nitrogen gas is termed de-nitrification or dissimilating nitrate reduction (DNR) (Jenicek *et al.*, 2004, Lai *et al.*, 2004). Biological de-nitrification is coupled to the respiratory electron transport chain; nitrate and nitrite are used as electron accept or for the oxidation of a variety of organic or inorganic electron donors (Turk *et al.*, 1987, Fux *et al.*, 2006).

As a simple word- De-nitrification is the conversion of nitrate (NO_3) to nitrogen gas (N_2) (Woolard *et al.*, 2004). Heterotrophic bacteria utilize the nitrate as an oxygen source under anoxic conditions to break down organic substances (Lai *et al.*, 2004).

- [Nitrates + Organics + Heterotrophic Bacteria = N_2 Gas & O_2 & Alkalinity]

A wide range of bacteria has been shown as capable of de-nitrification. Bacteria capable of de-nitrification are both heterotrophic and autotrophic (Hellinga C *et al.*, 1998). Most of these heterotrophic bacteria are facultative aerobic organisms with the ability to use oxygen as well as nitrate or nitrite, and some can also carry out fermentation in the absence of nitrate or oxygen (Metcalf and Eddy, 2003).

Biological de-nitrification involves the biological oxidation of many organic substrates in wastewater treatment using nitrate or nitrite as the electron acceptor instead of oxygen. The nitrate reduction reactions involve the different reduction steps from nitrate to nitrite, to nitric oxide, to nitrous oxide, and to nitrogen gas.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The electron donor as an organic substrate is obtained through the easily biodegradable COD in the influent wastewater (eq-12) or produced during endogenous decay, or an exogenous source such methanol (eq-13) or acetate (eq-14). Different electron donors give different reaction stoichiometry as observed below.

$$10NO_3^- + C_{10}H_{19}O_3N \longrightarrow 5N_2 + 10CO_2 + 3H_2O + 10OH^- + NH_3 \quad (12)$$

$$6NO_3^- + 5CH_3OH \longrightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^- \quad (13)$$

$$8NO_3^- + 5CH_3COOH \longrightarrow 4N_2 + 10CO_2 + 6H_2O + 8OH^- \quad (14)$$

The term $C_{10}H_{19}O_3N$ is often used to represent the biodegradable organic matter in Wastewater. In the above de-nitrification reactions, one equivalent of alkalinity is produced per equivalent of N-NO_3^-, which equates to 3.57 g of alkalinity (as $CaCO_3$) production per g of nitrate to nitrogen reduced. So, one-half of the amount destroyed by nitrification can be recovered (Metcalf and Eddy, 2003).

1.3.2 Biological Phosphorus Removal

The removal of phosphorus by a biological process is known as Enhanced Biological Phosphorus Removal (EBPR). Phosphorus removal is generally done to control eutrophication because phosphorus is a limited nutrient in most freshwater systems. The principal advantages of biological phosphorus removal are the reduction of chemical costs and lower sludge production than in chemical precipitation (Metcalf and Eddy (2003).

The enhanced biological phosphorus removal consists of incorporating the phosphorus present in the influent into cell biomass, which subsequently is removed from the process as a result of sludge wasting. The organisms responsible for this task are the phosphorus accumulation organism (PAO_S). To incorporate the phosphorus into the cell biomass, it is necessary to apply two different conditions, aerobic and anaerobic, in order to encourage the biomass to grow and consume phosphorus (Smolders *et al.,* 1994).

1.3.3 Some Benefits of Using SBR Treatment

- A higher degree of operational flexibility with respect to effluent quality and dissolved oxygen (DO) controlled aeration system
- Complete quiet settling for improved total suspended solids (TSS) removal
- A high degree of automation reduces operational staff requirements
- Significantly smaller footprint requires less site work on yard plumbing
- Lower initial capital cost and operating costs
- Power consumption is typically less than that of a conventional plant with substantial power savings at lower flows (i.e., greater turndown capability)
- Greater ability to meet effluent limitations (organic and nutrient)
- Better resistance to sludge bulking
- No need for external clarifiers
- Easily adaptable to nutrient removal
- Greater system flexibility and control
- Less land required and less equipment to maintain
- Can retrofit existing tanks, basins, ponds and convert to SBR

SBR technology has been proven on wastewaters from a wide variety of industries, including: Pharmaceutical, Pulp and paper, Corn wet-milling, Dairy processing, Chemicals production, Food processing, Meat processing, Yeast, Potato processing, Fish processing and Bakery.

1.4 MATERIALS AND METHODS

The obtained wastewater samples were analysed for: Total suspended solids (TSS), pH, DO (Dissolved Oxygen), Alkalinity, Turbidity, Total and soluble chemical oxygen demand (COD), Total and soluble biochemical oxygen demand (BOD), Ammonia ($N\text{-}NH_4^+$), Nitrates ($N\text{-}NO_3$), Phosphate ($P\text{-}PO_4^{3-}$).

1.4.1 Experimental Set-up: - The experiment set-up was located in a Paper Recycling Lab, Department of Paper Technology, IIT Roorkee (Saharanpur campus). The lab-scale SBR (Figure 2) consists of a cylindrical reactor working with maximum 15 litres volume and which could be adjusted to operate at a minimum volume of 4 litres (Which is the residual volume at the end of SBR).

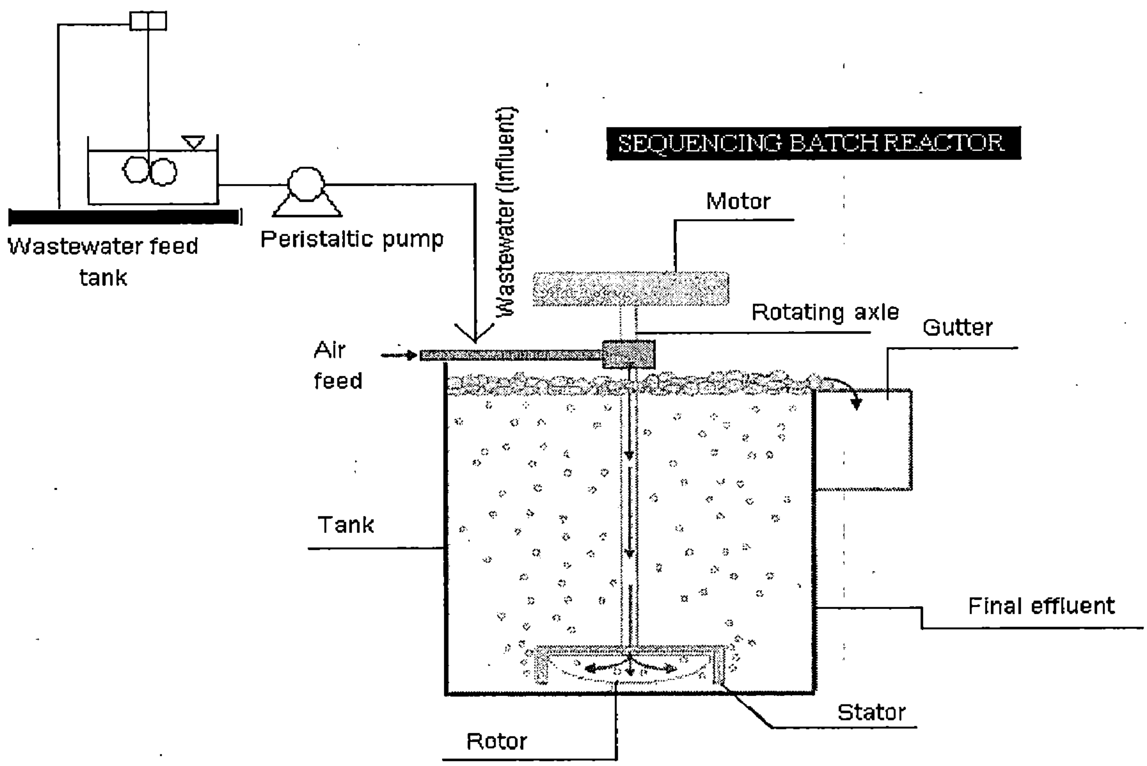

Figure 2: Schematic diagram of Sequencing Batch Reactor

The SBR was operated in a fill-React-settled-&-draw mode following a predefined cycle continuously. Required aeration and complete mixing was provided by an air pump connected to the network of diffusers arranged in the bottom of the reactor. During all filling & reaction phases, a diffused air device (a motor speed at 400 rpm) kept the reactor contents under homogenous conditions at all times. In these conditions, aerobic digestion by bacteria occurs in the presence of oxygen.

At the end of the reaction time and before the settling phase, excess biomass was removed from the reactor under aerobic condition. During extraction period, treated wastewater was discharged from the reactor until a predefined minimum reactor water level (for 4 litres) was reached. Effluent was discharged and collected in a plastic container for analysis. The temperature during the study period of 4 months varied from 21 to 38°C without any external control.

Sludge Removal: - Sludge produced is less and is totally digested and hence has no odour. The frequency of sludge removal will be around once in a month.

The SBR was operated on the basis of 1 cycle/day, that of 8 h duration. It consists of 4 hours mixing-reaction, 3 hours settling and 1 hour decanting.

1.4.2 Analytic Method

The analytical methods used during the whole experimental part are described below: pH, DO (Dissolved Oxygen), Alkalinity, Turbidity, Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biochemical oxygen demand (BOD), Volatile Ammonium (N-NH_4^+), Nitrates (N-NO_3^-) and Phosphate (P-PO_4^-).

Table 1. Analytic techniques adopted for physicochemical parameters.

SI. No.	Parameter	Principal	Instruments/Technique used
1.	Temperature	Metric	Thermometer
2.	pH	Metric	Digital pH meter
3.	D.O	Volumetric	DO meter
4.	Alkalinity	Volumetric	Titration method
5.	Turbidity	Volumetric	Digital Turbidity meter
6.	TDS	Volumetric	Digital TDS meter
7.	BOD	Volumetric	Modified Winkler's Method
8.	COD	Volumetric	Closed Reflux, Titrimetric method
9.	PO_4-P	Stannous Chloride Method	--
10.	NH_4-P	Phenate Method	--
11.	NO_3-N	Ultraviolet Spectro Photometric Screening	--

1.5 RESULTS AND DISCUSSION

1.5.1 Methodology

The reactor performance was monitored throughout the experimental work at least thrice a week though the determination of COD, BOD, TSS, P-PO_4^-, N-NO_3^-, and N-NH_4^+ in the influent and the effluent. The samples were collected from near to Vishwakarma chowk canal (Saharanpur city) at different intervals of time in a day and on different days.

1.5.2 Monitoring for Nutrient Removal

Microbial activity in the organic matter and nutrient removal involve physical and chemical changes which can detect monitoring of pH and Dissolved Oxygen (DO) during a cycle.

The major characteristics of the municipal sewage and the treated effluent are given in Table 2. The reactor was in operation for 44 days, out of which complete or partial data of 32 days was collected in all. As a result, performance evaluation on the basis of individual parameters is done for less than 32 days in most of the cases. Since, all the parameters were not monitored on daily basis; therefore the numbers of samples tested are mentioned along with the standard deviation of the effluent quality.

As compared to conventional activated sludge reactor, the SBR is intermittent, both in terms of operation as well as oxygen demand, which is typically higher in the beginning than towards the end of the aeration phase. Achieving reasonably high efficiency under extremely wide fluctuations in almost all the operating parameters as mentioned below, indicates the sturdy nature of SBR even under continuous feed mode and actual varying conditions, at the same time sludge reduction under high DO is also tested

Table 2. Characteristics of SBR influent and effluent *

Parameters	No. of Samples	SBR Influent (avg.)	SBR Effluent (avg.)	% Removal (avg. ±σ)
pH	32	5.18-8.14 (7.37)	7.32- 8.29 (7.75)	--
DO (mg/l)	32	0.63-1.22 (0.87)	0	--
Alkalinity (mg/l as CaCO3)	32	128-410 (307.54)	202-428 (292.70)	--
Turbidity (NTU)	32	10.6-119 (65.17)	0.156-15.9 (4.00)	82.18-99.54 (93.01±.17)
TSS (mg/l)	18	58-289 (154.79)	7-33 (14.33)	77.24-92.68 (88.34± 3.97)

TBOD(mg/l)	18	78-176 (107.67)	3-20.1 (8.58)	89.80-98.81 (94.57±5.47)
SBOD (mg/l)	18	44-100 (74.92)	0-22 (4.84)	80.00-100 (94.27±4.74)
TCOD(mg/l)	35	60.32-1076.4 (240.29)	2.76-72 (15.05)	58.99-98.90 (92.12±9.45)
SCOD(mg/l)	33	9.5-97.5 (33.54)	0-53.94 (18.77)	30.55-100 (90.52±3.96)
NH_3-N (mg/l)	17	10.00-58.40 (37.38)	0.00-5.34 (2.10)	89.21-100 (94.30±3.83)
NO_3-N (mg/l)	16	0.13-11.5 (3.64)	6.70-26.33 (17.26)	--
PO_4-P (mg/l)	16	0.3-4.56 (2.82)	0.38-5.46 (2.67)	--

*** Average values are given in parentheses ±σ.**

pH: -The change in pH value during a cycle of a biological system responds to microbial reaction and hence the pH variation often provides a good indication of ongoing biological reaction. Different critical points can be detected in the pH curve.

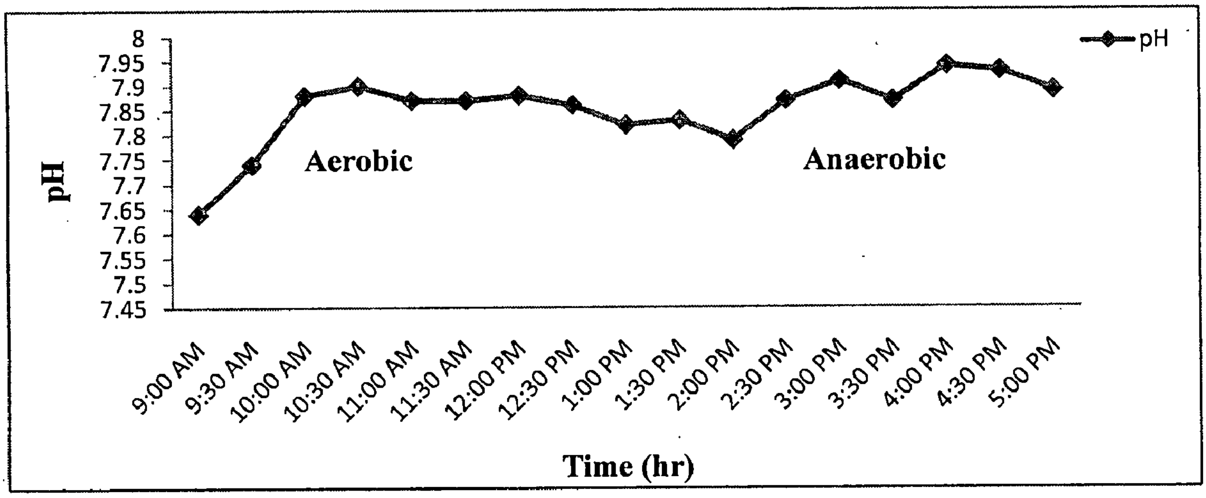

Figure 3: pH profile

If only organic matter is obtained under aerobic conditions, the pH is affected by the stripping of CO_2 and as a consequence an increase of pH occurs (Figure 3, left side).

In systems where carbon and nitrogen removal are required, the pH can present two critical points; Ammonia Valley and Nitrate Apex. These points can appear in the pH curve when nitrification and de-nitrification occurs. Under aerobic conditions, CO_2 is expelled from the solution by air-stripping initially raises pH, the reduction of alkalinity by prevailing nitrification decreases the pH until it reaches a minimum (Figure 3, right side). This minimum in the pH profile is called Ammonia Valley and corresponds to the end of

nitrification. After the ammonia valley, the pH increases due to the stripping of CO_2. The pH variation range depends on the wastewater alkalinity.
Under anoxic conditions and if organic matter is available, ongoing de-nitrification increases the pH of the system. There after the pH reaches to an inflection point before decreasing slightly (Figure 3, right side).

Dissolve Oxygen (DO): -The change in the Dissolved Oxygen (DO) curve responds to microbial reactions, microorganisms utilize oxygen as an electron acceptor under aerobic conditions. Under a constant oxygen supply by the diffused air device (a motor speed at 400 rpm).

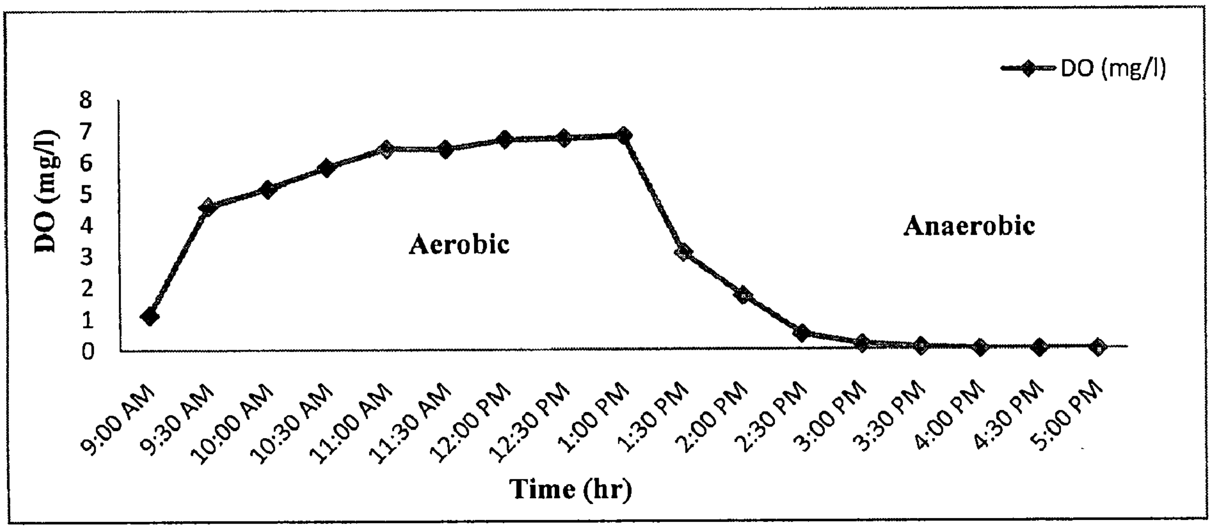

Figure 4: DO profile

Under aerobic phases the organic carbon oxidation is very high and requires a large quantity of oxygen which causes a DO decline to a low level in the reactor. When organic matter is close to being completely removed, a sudden DO increase is observed. Afterwards, the main reaction is the oxidation of ammonia (nitrification) and here the DO rises progressively.

BOD and COD Removal: -The total BOD, COD and their soluble fractions of the influent and effluent were monitored at a regular interval as shown in Figures 5 to 8. Irrespective of influent BOD variation, on more than 85% occasion, the effluent BOD was less than the stipulated disposal standard of 30 mg/l, resulting in more than 94% average removal. Similarly, the average total COD removal was more than 92%.

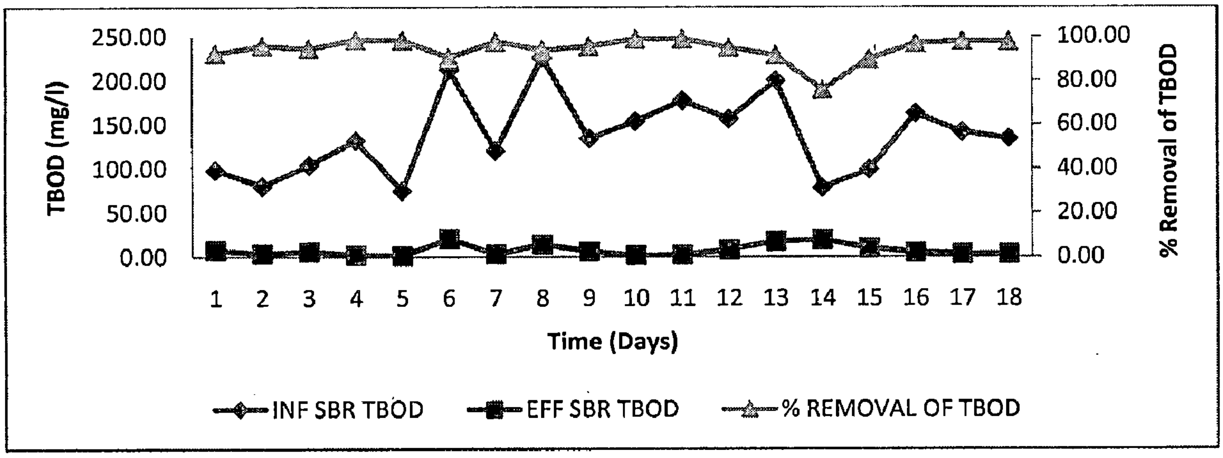

Figure 5: Variation in influent, effluent TBOD concentrations and % removal

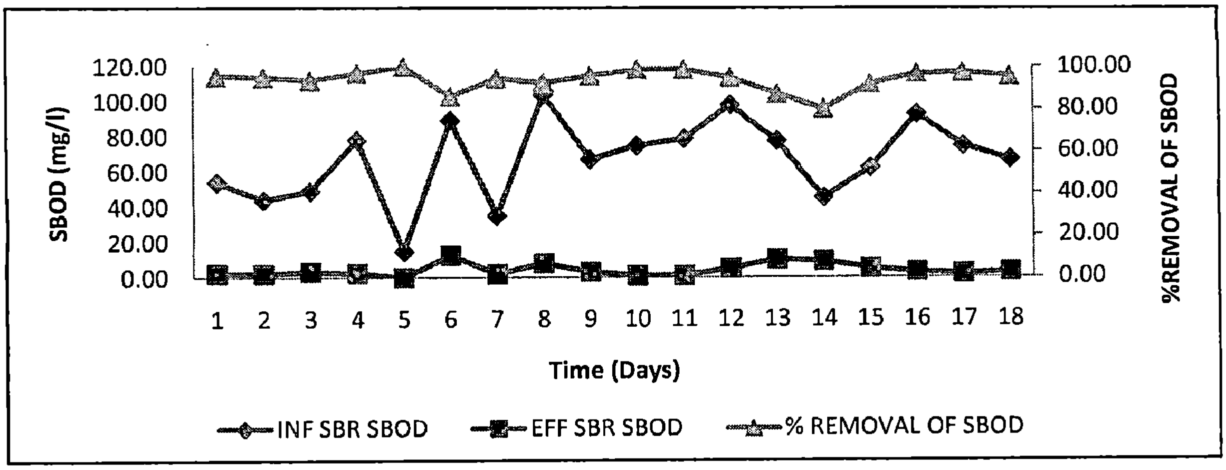

Figure 6: Variation in influent, effluent SBOD concentrations and % removal

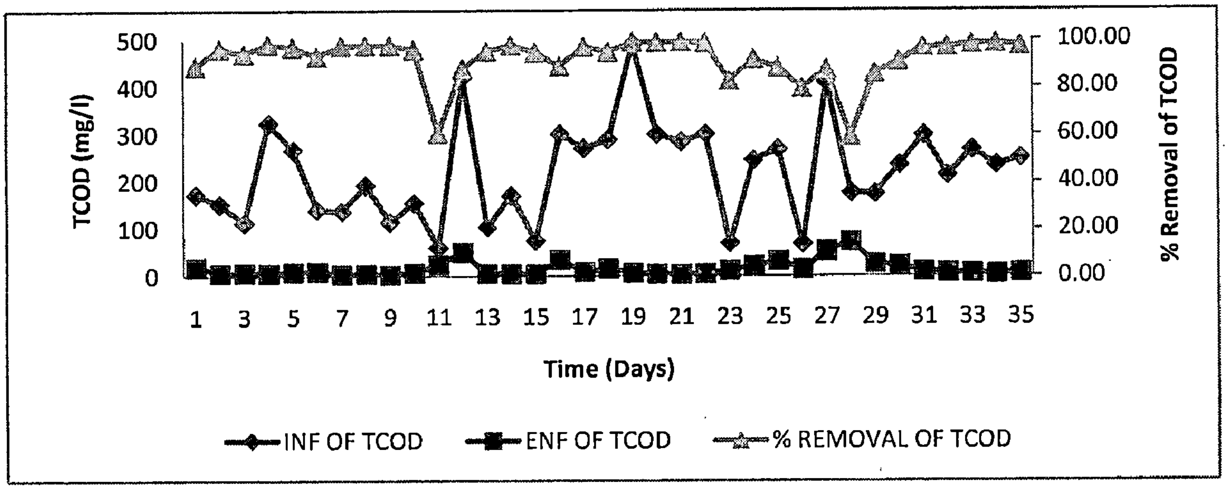

Figure 7: Variation in influent, effluent TCOD concentrations and % removal.

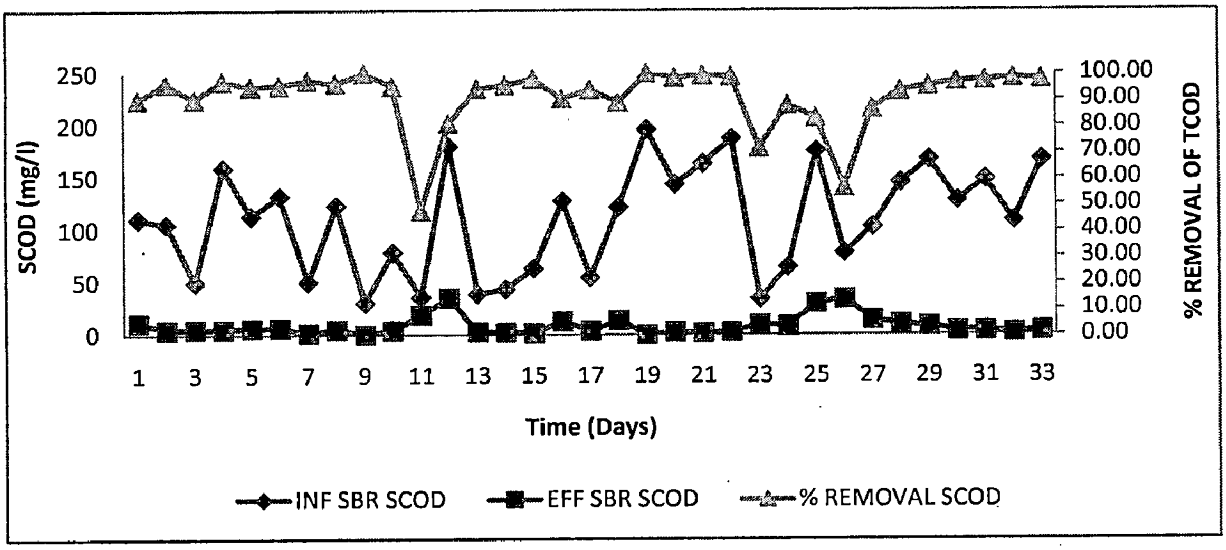

Figure 8: Variation in influent, effluent SCOD concentrations and % removal.

Ammonical Nitrogen Removal: - The observations revealed that SBR efficiently removes ammonical from the raw sewage (Fig. 9) at the average rate of 94.30±3.83%. Higher efficiencies could be presumed under normal operating conditions, in addition to the above mentioned facts the reasonable efficiencies could be attributed to prevalence of anoxic conditions in the pre-react zone and availability of carbon source due to continuous feed causing de-nitrification of whatever nitrate available at that stage.

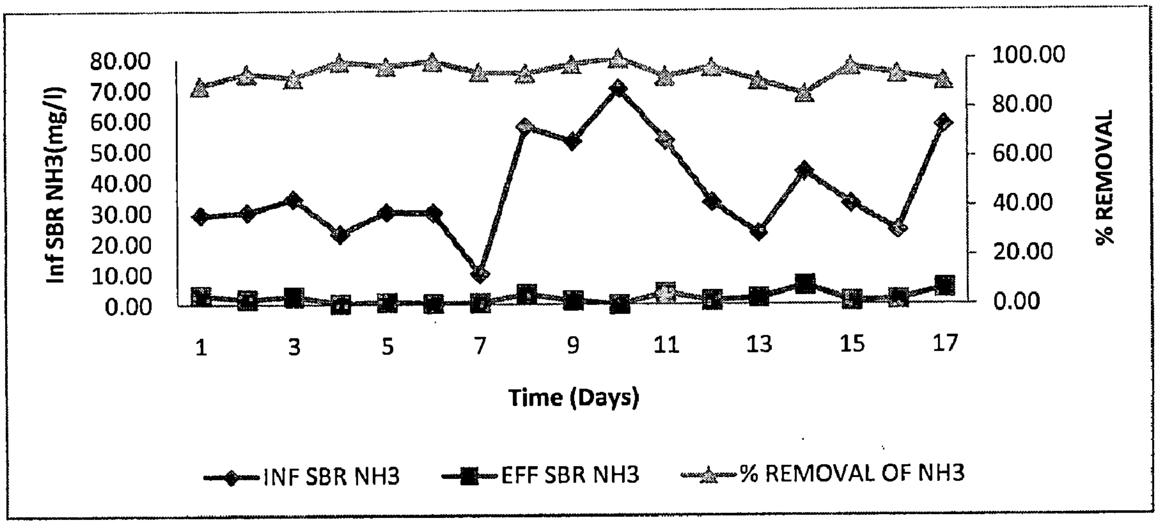

Figure 9: Temporal variation in ammonical nitrogen removal

Phosphorus Removal: - The average orthophosphate concentration in feed and treated effluent ranges 0.3 – 4.56 mg/L and 0.38-5.46 mg/L, resulting in negligible removal (Fig. 10), which is expectedly low in the absence of any anaerobic pre-treatment.

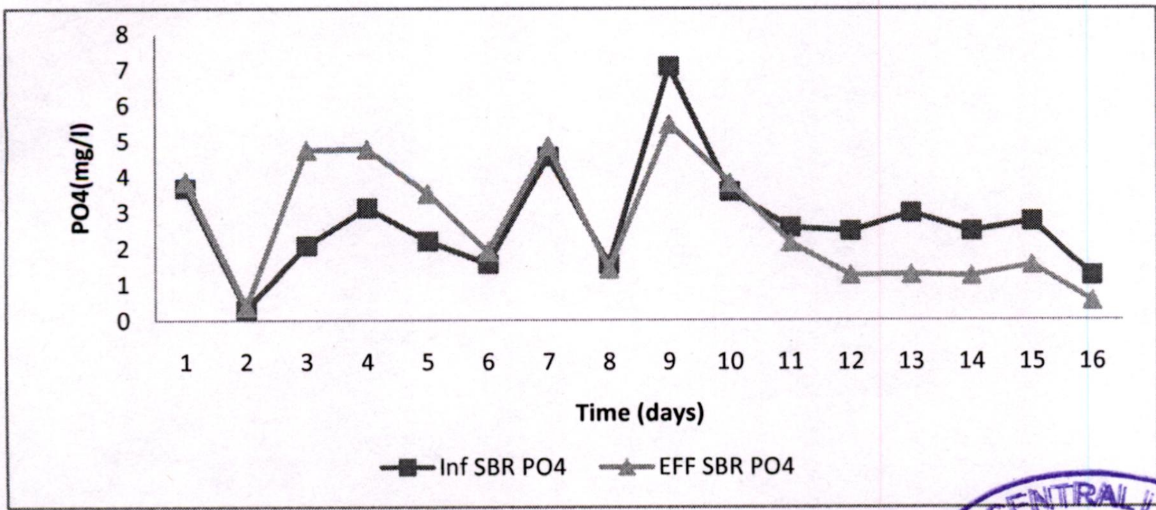

Figure 10: Variation in influent, effluent PO4-P concentration.

TSS Removal: - TSS in influent and effluent was daily analyzed and the average values were 126.06 mg/L and 14.33 mg/L respectively, resulting in 88.34% efficiency (Fig 11). A slightly higher effluent TSS (33.8mg/l > 30mg/l) indicated that settling of sludge was not proper during settling and decantation phase. The intermittent presence of pin point floc in effluent could be another possibility as it increased the effluent turbidity and TSS as well.

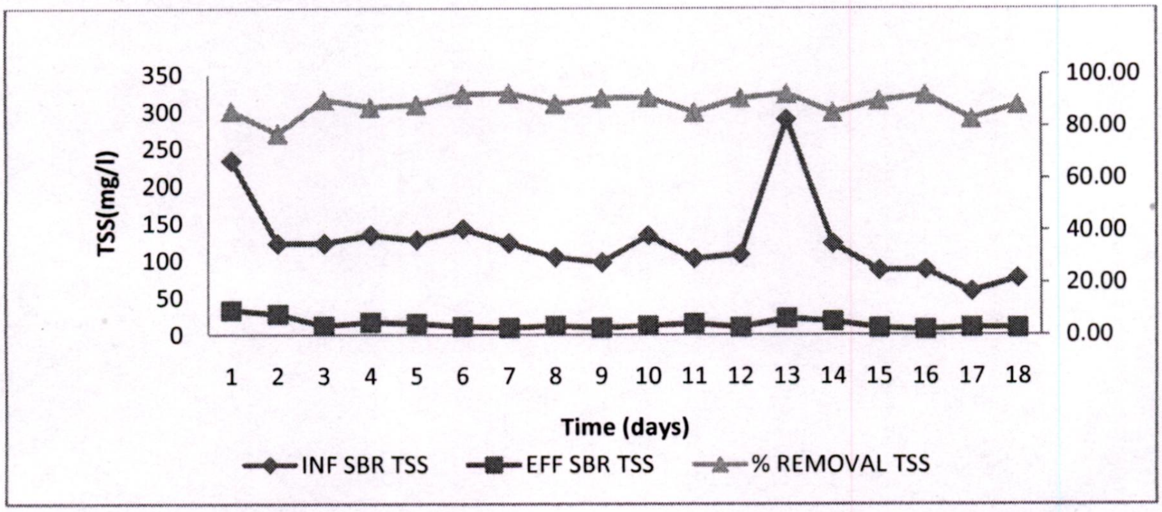

Figure 11: Variation in influent, effluent TSS concentration and % removal.

CHAPTER-2

Purification by water-hyacinth (*Eichhornia crassipes*)

2.1 SUMMARY

Water hyacinth just one of the great number of aquatic plant species successfully used for wastewater treatment. The aim is to determine the feasibility of water hyacinth in treating wastewater. It is important to emphasize that water hyacinth has a huge potential for removal of the vast range of pollutants like suspended materials, BOD, nutrients, and organic matter from wastewater. At the same time water hyacinth is one of the most notorious weeds worldwide. When introduced to aquatic ecosystem it spreads very quickly with high reproduction potential. Therefore water hyacinth tends to eliminate all other living organisms in surrounding.

The initial pungent odour of the wastewater gradually disappeared during the purification period while the light yellowish colour turned almost colourless in the final effluent sample. It was determined that the final effluent from water-hyacinth could be used for irrigation and recycled to a flowing stream for other uses except for drinking purposes.

2.2 INTRODUCTION

Water pollution is one of the most serious problems of today's civilization. The consumption of water has been doubling on every twenty years but the reduction of this period is expected if today's trends in water use continue (Velasevic and Djorovic, 1998). These two statements justify people's fear that whole areas of the world will remain without biochemical safe water suitable for drinking and other needs. One can say situation is already alarming if it is known that because of fresh water disposition on Earth only one third of its territory is well provide with water, and if drastic efforts in water protection are not made by year 2025, 2.3 billion people will live in areas with chronic water shortage (WHO, 2005).
There are many technologies for wastewater treatment that can help in re-establishing and preserving physical, chemical and biological integrity of water.

All of these technologies can be classified in two basic groups:

I. Conventional methods for purification of wastewater (wastewater treatment is carried out by physical, chemical and biological processes)

&

II. Alternative methods for purification of wastewater (wastewater treatment is carried out by imitating self-purification process).

Today these conventional wastewater treatment facilities fail in satisfying all the demands of ecologically aware societies. This is because they: do not harmonize with basic principles of water conservation, do not enable reclamation and reuse of water and nutrients, generate toxic sludge as by product and use chemicals, harmful to environment and people, in the treatment process (Davis for EPA, 2004). So researches sought for other solutions that will go beyond all problems mentioned above. All of the answers were found by wastewater purification by aquatic plants.
There are many different types of these alternative systems (aquatic systems) but all of them have the same major characteristic - thanks to symbiotic relationships between their basic components, aquatic plants (Peterson and Teal, 1996), microorganisms (Perkins and Hunter, 2000), Algae, substrates and water have the ability to remove organic and inorganic matter, nutrients, pathogens, heavy metals and other pollutants from wastewater (Naranjo, 1993;

Peterson and Teal, 1996; Redding *et al.*, 1997; Knight *et al.*, 1993; Hammer, 1989) in a completely natural way (House *et al.*, 1999; Verhoeven and Meuleman, 1999).

Water hyacinth (Eichhornia crassipes), a wild fern belonging to the family pontederiaceae, is a submerged aquatic plant, found abundantly throughout the year and is commonly available in India (Mohanty *et al.* 2006; El-Khaiary 2007). One of the fastest growing plants known, water hyacinth reproduces primarily by way of runners or stolons, which eventually form daughter plants. It also produces large quantities of seeds, which are viable up to thirty years. It is a vigorous grower, known to double its population in one month and has been considered to be the least desirable aquatic plant (El-Khaiary 2007).

In last few years a great deal of interest has been shown in India for introduction of water hyacinth (aquatic plant) and construction of aquatic systems for wastewater treatment (Lindsey K. *et al.* 1999).

2.2.1 Water hyacinth morphology

Water hyacinth is aquatic vascular plant with rounded, upright and shiny green leaves and lavender flowers similar to orchids (U.S. EPA, 1988). Individual rosette is erect and free floating with numerous stolons (Center *et al.*, 2005). Each one carries six to eight spirally arranged succulent leaves that are produced sequentially on a short vertical stem. Petioles are bulbous and spongy with many air spaces (U.S. EPA, 1988) which allow plants to float on a water surface. But floating leaves can vary in size and morphology primary according to growth conditions and the stage of colony development. Leaves with bulbous petioles are dominant in open water whereas elongated petioles (up to 1.5 m in height) predominate in dense colonies (Center *et al.*, 2005). The inflorescence consists of ten to thirty flowers with six violet blue or violet pink petals (Center *et al.*, 2002). Top petal has gold yellow spot bordered with blue line which resembles the pattern of peacock eye (Aquatics, 2005; APIRIS, 2005). Root system of water hyacinth is dark blue in colour (Aquatics, 2005; APIRIS, 2005) with numerous stolons. New plants are formed at the end of these stolons. Measured from flower top to root top *E. crassipens* usually reaches a height of 30-40 cm, with short stem containing leaf and many long fibrous roots (Fig. 12). These plants are sometimes floating and sometimes rooting.

Water hyacinth can be divided in five parts leaves, leaf stalk, rhizome, stolon and root.

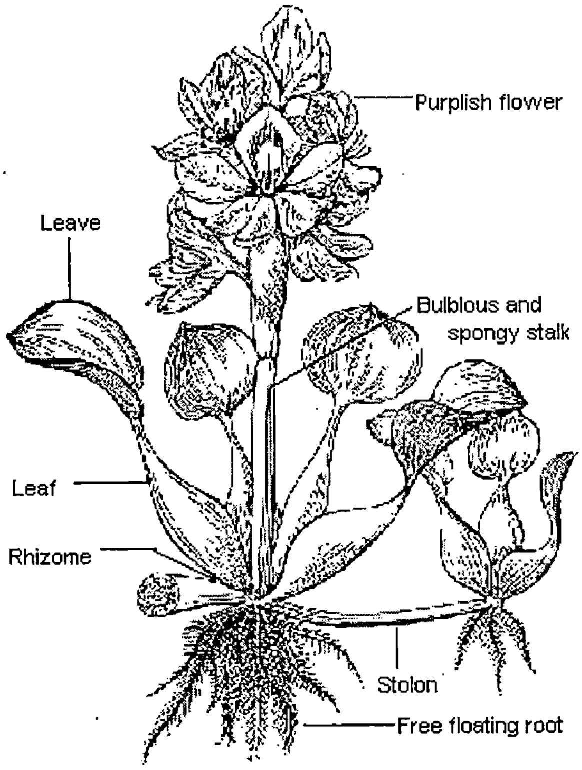

Figure 12. Water hyacinth (*Eichhornia crassipes*).

2.2.2 Identifying Characteristics

Size/Form Water hyacinth is an emergent, aquatic perennial, with thick, spongy leaves and spike-like floral stalks, which may grow up to 3' tall. The plants have fibrous, black roots.

Leaves The leaves are simple, alternately-arranged and oval to elliptical, with a sub-circular base. The thick, leathery, spongy leaves often curl inward around the leaf base. Venation is parallel.

Fruit The fruit is a three-celled capsule, containing many, small seeds. The flowers are loose, spike-like clusters of tiny lavender blossoms, borne on upright stalks.

Stem The stem is thick and spongy, with an inflated bulb visible on the lower stem.

Habitat Water hyacinth grows in shallow, fresh water wetlands. It is often seen in pure stands along the edges of ponds, lakes, canals, ditches and slow-moving streams.

2.3 LITERATURE SURVEY

Water hyacinth (*E. crassipens*) is fast growing perennial aquatic macrophyte (Reddy and Sutton, 1984). It is a member of pickerelweed family (*Pontederiaceae*) and its name *Eichhornia* was derived from well known 19th century Prussian politician J.A.F. Eichhorn (Aquatics, 2005). This tropical plant spread throughout the world in late 19th and early 20th century (Wilson *et al.*, 2005). Today it is well known for its reproduction potential (de Casabianca and Laugier, 1995) and as a plant that can double its population in only three month (APIRIS, 2005). Water hyacinth is also known for its ability to grow in severe polluted waters (So *et al.*, 2003). *E. crassipens* is well studied as an aquatic plant that can improve effluent quality from oxidation ponds and as a main component of one integrated advanced system for treatment of municipal, agricultural and industrial wastewaters (U.S. EPA, 1988; Sim, 2003; Wilson *et al.*, 2005; Chua, 1998; Mangabeira *et al.*, 2004; de Casabianca ang Laugier, 1995; Maine *et al.*, 2001). To regret, water hyacinth is often described in literature as a serious invasive weed (Wilson *et al.*, 2005; U.S. EPA, 1988; Maine *et al.*, 1999; So *et al.*, 2003; Singhal and Rai, 2003) and it is ranked on eighth place in the list of world's ten most serious weeds (Reddy and Sutton, 1984).

2.3.1 Taxonomy

Cronquist (1988), Thorne (1992) and Takhtajan (1997) have suggested the following water hyacinth taxonomic placement (Center *et al.*, 2002):

- **Division:** - *Magnoliophyta*
- **Class:** - *Liliopsida*
- **Subclass:** - *Commeinidae*
- **Super order:** - *Commelinanae*
- **Order:** - *Pontederiales*
- **Family:** - *Pontederiaceae*
- **Genus:** - *Eichhornia*
- **Specific epithet**: - *crassipes* (Martius) Solms-Laubach.

2.3.2 Ecological factors and reproduction

As mentioned above, *E. crassipens* is a fast growing perennial with great reproduction potential. Growth of water hyacinth is primarily dependant on: ability of plant to use solar energy, nutrient composition of water, cultural methods and environmental factors (U.S. EPA, 1988).

Plant growth is described in two ways:

- First is by reporting the percentage of water surface covered for a period of time.
- Second and more useful method is by reporting the plant density in units of wet plant mass per unit of surface area (U.S. EPA, 1988).

Water hyacinth is growing fastest at temperatures from 23 to 35^{0}C but temperatures above 33^{0}C inhibit further growth (Knipling *et al.*, 1993; cit. Center *et al.*, 2002) and growth fully stops at temperatures from 0 to 6^{0}C (Stephenson *et al.*, 1980). Optimal water pH for growth of this aquatic plant is neutral but it can tolerate pH values from 4 to 10 (Haller and Sutton, 1973, cit. Center *et al.*, 2002). This is a very important fact because it points that *E. crassipens* can be used for treatment of different types of wastewater. Low air humidity from 15% to 40% can also be limiting factor for undisturbed growth of water hyacinth (Allen, 1997).

This aquatic plant can reproduce in both generative and vegetative ways. That means new plants can be produced from seeds or they represent clones derived from stolon elongation due to division of auxiliary meristems of mother plant (Center *et al.*, 2005). At first these new rosettes are attached to mother plant but stolons are very fragile so they easily break enabling young individuals to float away and colonise new areas (Wilson *et al.*, 2005; Center *et al.*, 2005). Water hyacinth is mainly reproduced by generative means in its natural habitat and it produces large number of seeds (Wilson *et al.*, 2005; Center *et al.*, 2005). Seeds usually germinate within 6 months but in wet sediments at the bottom they can contain germination for 15 to 20 years (Center *et al.*, 2002). Seeds germinate in moist environment in sediments or in warm shallow water (Center *et al.*, 2002) and after 30 to 40 days seedlings have 4 to 8 leaves (Wilson *et al.*, 2005).

So when maintaining and monitoring aquatic ecosystems or aquatic systems, one must have in mind that where ever water hyacinth can produce new plants from seeds, generative reproduction must not be underestimated.

Water hyacinth systems were used mostly in regions with warm climate because of plant sensitivity to low temperatures and frost. The aquatic systems consist of one or more shallow basin in which one or more aquatic vascular plant species are grown (Tchobanoglous, 1987). Wastewater purification is principally carried out by bacterial metabolism and physical sedimentation (U.S. EPA, 1988). Aquatic macrophytes themselves, do not contribute much in pollutant removal (Tchobanoglous, 1987). Their role is in providing other components of aquatic system that improve wastewater treatment capability (Reed and Bastian, 1980). The root of water hyacinth acts like living substrate for attached microorganisms which then provide a significant degree of treatment, thanks to their metabolism (U.S. EPA, 1988). Besides enabling growth of microbial colonies, root system is also a good medium for filtration and adsorption of suspended materials, nutrients and heavy metals (Center *et al.*, 2002).

2.3.3 Control of water hyacinth

Excessive growth of water hyacinth populations can be inhibited by biological, mechanical and chemical control measures.

Biological control is the most environmentally friendly measure but there are some very important things to think about before using it. **First,** when choosing species that will perform biological control, it is not enough for them to be just natural enemies of water hyacinth. There are many cases where introduced species did not perform well in new habitat because they have found new hosts and instead of destroying *E.* Crassipens, they started to reduce other aquatic macrophytes populations. **Second,** problem can be their acclimatisation especially if they were introduced to colder climates. In early 1970s, the CIBS (Central Institute of Bioscience) have released three natural enemies for the purpose of biological control of this aquatic weed. These biological agents were two weevils *Neochetina eichhorniae* Warner and *N. bruchi* Hustache, and later the pyralid moth *Niphograpata albiguttalis* (Warren) (Center *et al.*, 2002; Grodowitz *et al.*, 1997; Wilson *et al.*, 2005). Besides, these three insects of Argentinean origin now widely used, is also the mite *Orthogalumna terebranti* (Wall work) (Center *et al.*, 2002).

Today there is also a great deal of interest for the use of plant pathogens, phytotoxins or their derivates as agents for biological control of this notorious aquatic weed. The most studied and used are fungus *Alternaria eichhorniae* Nag Raj and Ponnappa Sp. Nov., *A. alternata* (Fr.) and *Cercospora piaropi* Tharp. *(Center et al., 2002; Babu, 2003).*

So many insects, mites and fungus have been released in many locations in tropics and they have drastically reduced further spread of water hyacinth (Wilson et al., 2005; Julien and Orapa, 1999). But there are still many questions about their efficiency worldwide and water authorities are sometimes pointing to fact that biological control is too slow (Wilson et al., 2005; Center *et al.*, 2002). Because of that, there is still a tendency for applying mechanical and chemical control measures which are not always acceptable.

Mechanical control is often reduced to cutting and sometimes burning of water hyacinth (Babu, 2003). When using cutting as control measure, the major problem is great plant biomass. Cutting machines are quickly filled so the whole operation is very slow and expensive. This problem was solved to a certain degree by different improved models of cutting machines but there is still affinity for use of quicker and cheaper methods and that is usually the use of chemical control measures (Grodowitz *et al.*, 1997). Of course the instantaneous removal of aquatic weed will be attained quickest by applying herbicides but it can lead to additional load and damage of sensitive aquatic ecosystems and pollution of whole environment. Long term application of same herbicides can also lead to appearance of plant resistance (Babu, 2003).

All control measures mentioned above have many advantages and constraints so in the future it would be wise to use integrated control measures against water hyacinth (Babu, 2003). It should be pointed out that fast growth and rapid spread of water hyacinth are often consequences of large quantities of nutrients and other pollutants present in water contaminated with effluents from agriculture, industry, municipalities and other sources (Grodowitz *et al.*, 1997; Wilson *et al.*, 2005) so the presence of *E. crassipens* is not always a problem itself. In this case spending the whole wealth on different control measures would be just avoiding the real problem.

Water hyacinth has also influence on frequently occurring diseases (dysentery, malaria, schistosomiasis) related to content of different pathogens in water (National Geographic, 2004). It is strongly considered that this is happening because the dense mats of *E. crassipes* prevent normal water circulation, thus creating places with stagnant water suitable for development of various pathogens (National Geographic, 2004). This requires frequent checking of treated water going out from the treated ponds.

The aim of this study was to developing and improving the biological nutrient removal from municipal wastewater to reuse in ours daily life.

2.4 MATERIALS AND METHODS

This chapter describes the collection of water hyacinth plants, the experimental setup along with the experiments performed and performance of water hyacinth in treating waste water were analysed.

In order to evaluate the performance of the treatment of Municipal Wastewater: Total suspended solids (TSS), pH, DO (Dissolved Oxygen), Alkalinity, Turbidity, Total and soluble chemical oxygen demand (COD), Total and soluble biochemical oxygen demand (BOD), Ammonia ($N\text{-}NH_4^+$), Nitrates ($N\text{-}NO_3$), Phosphate ($P\text{-}PO_4^{3-}$) were analysed.

2.4.1 Plant Samples and Experimental Set-up

Young water hyacinth plants with a similar shape were collected from ponds near Gita Pump House (Paper Mill Road, Saharanpur) and washed with water to remove dirt. All water hyacinths were grown in four large size plastic buckets. All plastic buckets were of 15 liters capacity. In each bucket, plants were grown in 10 liters of municipal wastewater. When the level of wastewater in the buckets went down due to evaporation and absorption by the plants for growth, distilled water was added to make up the level. Batch studies were performed to get weekly analysis of pH and DO and rest of other parameters were analysis as initial and final prefatory.

The experiment set-up was prepared in the Paper Recycling Lab, Department of Paper Technology, IIT Roorkee (Saharanpur campus). A 28-day experiment was performed under natural conditions and temperature during the experimental period of one month. Temperature varied from 17 to 38°C without any external control.

Figure 13. Experimental Setup for Batch Studies

2.5 RESULTS AND DISCUSSION

pH & DO: - The pH of the effluent showed very little fluctuation in the four experimental periods involving water hyacinth. The maximum pH value recorded of influent was 7.86 and the minimum was 6.12 while the maximum and minimum values of effluent were 7.23 and 6.02 respectively and the maximum DO value recorded of influent was 0.96 and the minimum was 0.12 mg/l while the maximum and minimum values of effluent were 0.1 and 0.00 mg/l respectively. The bucket effluent was also dark in colour and emitted odours at night when the plants were photo synthetically inactive and did not remove the sulphur-containing gases, such as hydrogen sulphide.

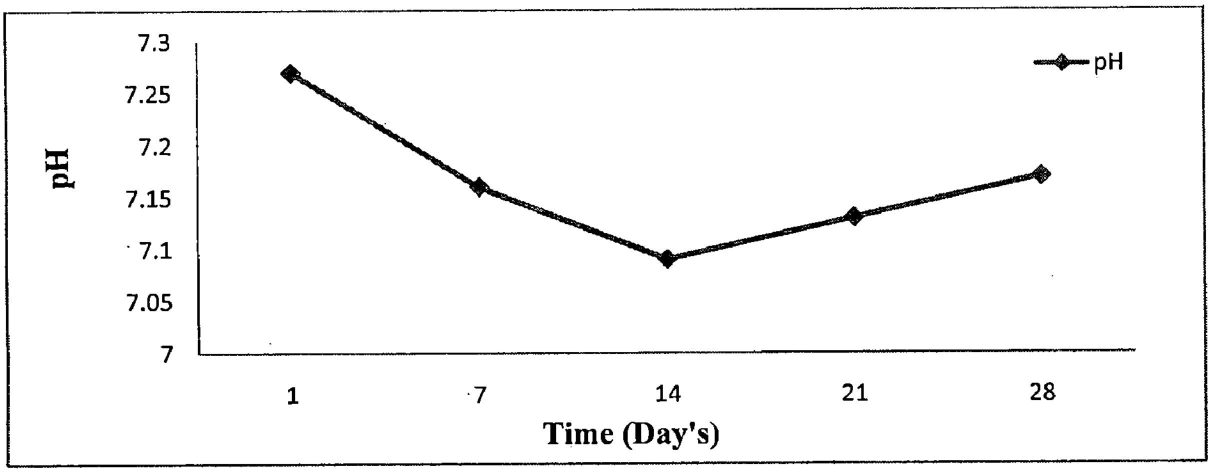

Figure 14: pH profile

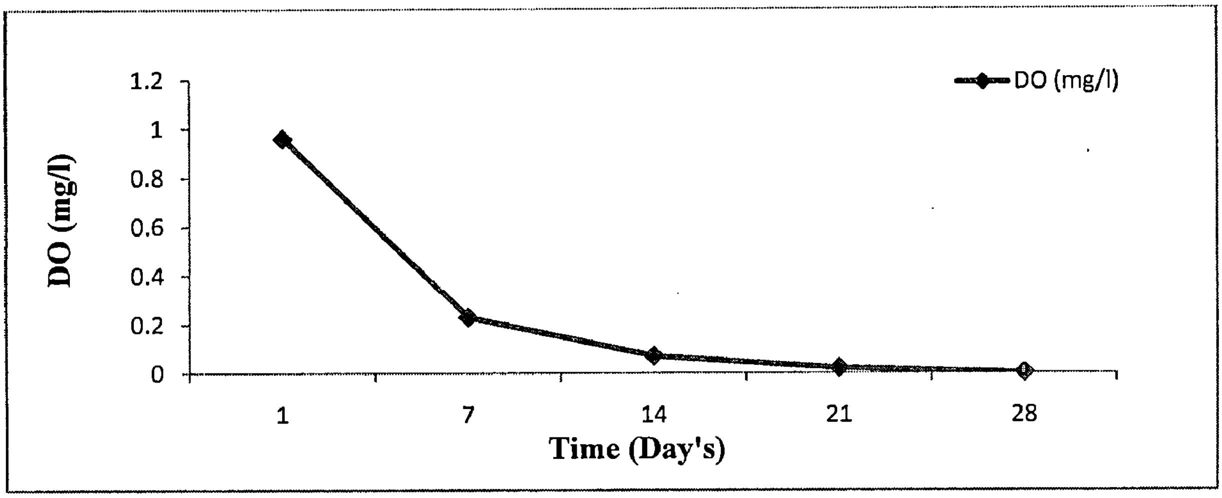

Figure 15: DO profile

Table 3. Characteristics of influent and effluent*

parameter	No. of System	Influent (avg.)	Effluent (avg.)	%Removal (avg. ±σ)
pH	4	6.12-7.86 (7.19)	6.02-7.23 (6.87)	--
DO (mg/l)	4	0.12-0.96 (0.62)	0.00-0.10 (0.04)	--
Alkalinity (mg/l as CaCO3)	4	112.68-178.67 (149.71)	96.12-148.30 (129.13)	0.96-16.73 (13.54±3.06)
Turbidity (NTU)	4	36.53-72.61 (57.08)	2.37-6.52 (4.38)	89.37-96.73 (92.02 ±3.27)
TSS(mg/l)	4	137.32-183.68 (160.48)	48.95-66.91 (57.30)	59.36-68.96 (64.15±3.94)
TBOD(mg/l)	4	83.47-119.73 (101.67)	25.56-40.30 (31.71)	62.28-73.17 (68.88±4.67)
SBOD (mg/l)	4	9.58-16.73 (12.57)	2.68-5.23 (3.94)	64.28-71.93 (68.89±3.35)
TCOD(mg/l)	4	426.29-573.30 (505)	206.87-316.27 (264.08)	43.89-51.47 (47.93±3.12)
SCOD(mg/l)	4	23.96-56.38 (34.44)	14.07-35.24 (23.33)	34.16-41.26 (37.87±2.93)
NH_3-N (mg/l)	4	17.71-38.72 (26.68)	5.50-8.37 (6.38)	72.92-78.36 (74.52±4.09)
NO_3-N (mg/l)	4	0.72-3.41 (2.02)	0.63-4.16 (2.17)	--
PO_4-P (mg/l)	4	0.96-1.86 (1.36)	0.32-0.91 (0.57)	25.19-49.26 (40.73±1.29)

*** Average values are given in parentheses ±σ.**

BOD AND COD: - The total BOD, COD and their soluble fractions of the influent and effluent were monitored at a regular interval as shown in Figures 16 to 19. The mean BOD of the influent was 101.67mg/l (range 83.47mg/l-119.73mg/l). The maximum and minimum values of BOD of the effluent were 40.30 mg/l and 25.56 mg/l respectively with a mean value of 31.71 mg/l and 68.89% is average removal. Similarly, the mean COD values of influent and effluent of system during study period was 505 mg/l and 264.08 mg/l (i.e. a mean reduction of 47.93%). The COD values of the influent and effluent varied from 426.29 mg/l to 573.30 mg/l and 206.87 mg/l to 316.27 mg/l.

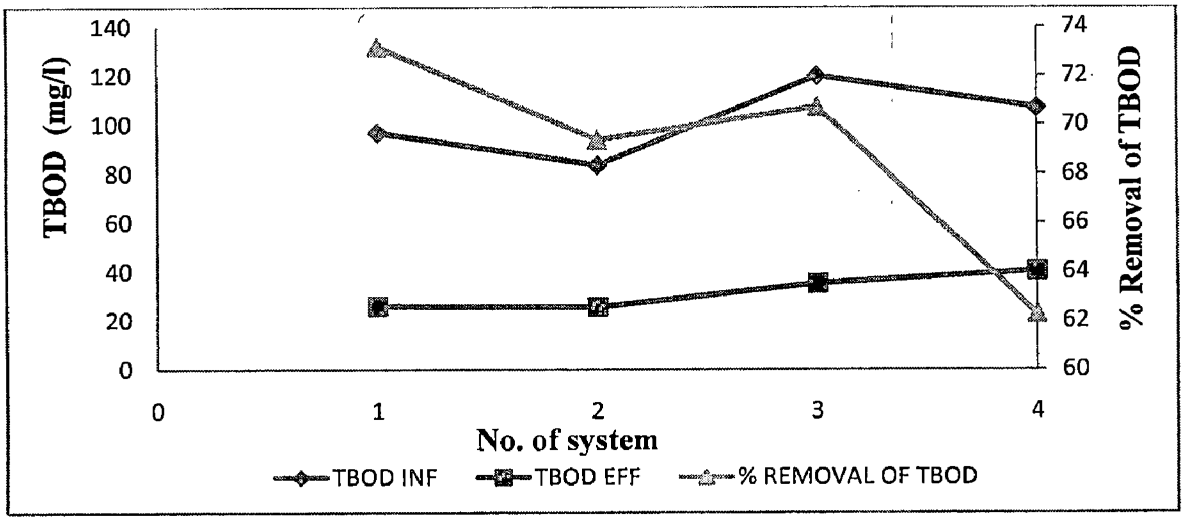

Figure 16: Variation in influent, effluent TBOD concentrations and % removal

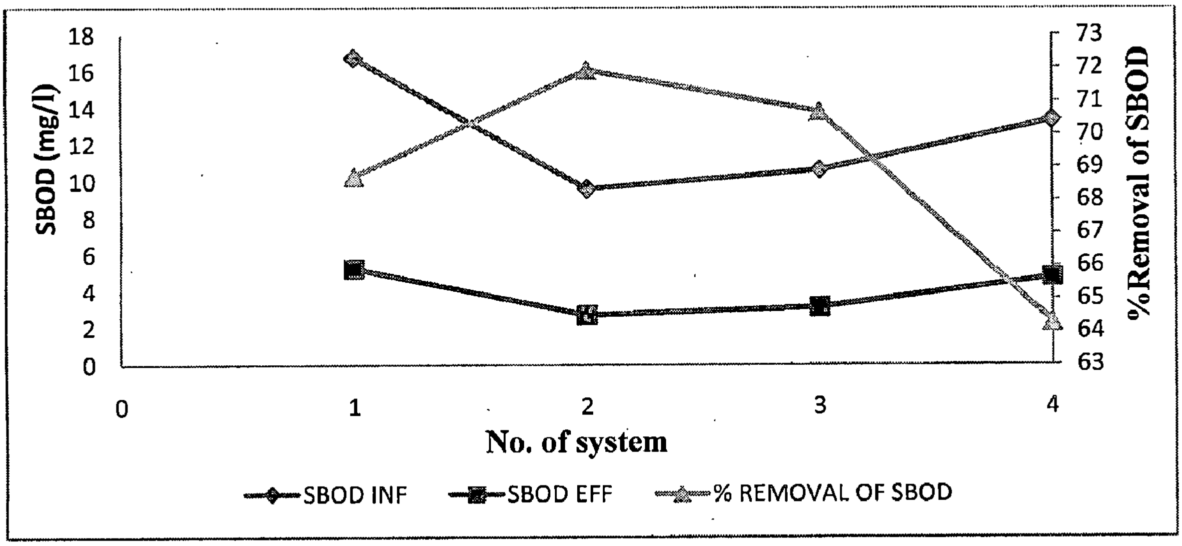

Figure 17: Variation in influent, effluent SBOD concentrations and % removal

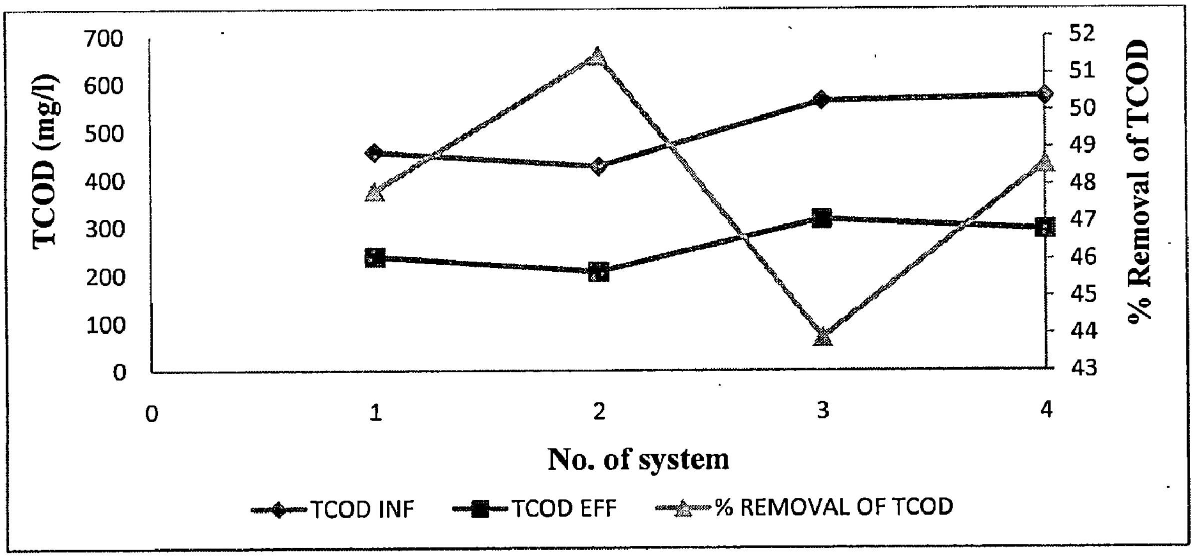

Figure 18: Variation in influent, effluent TCOD concentrations and % removal.

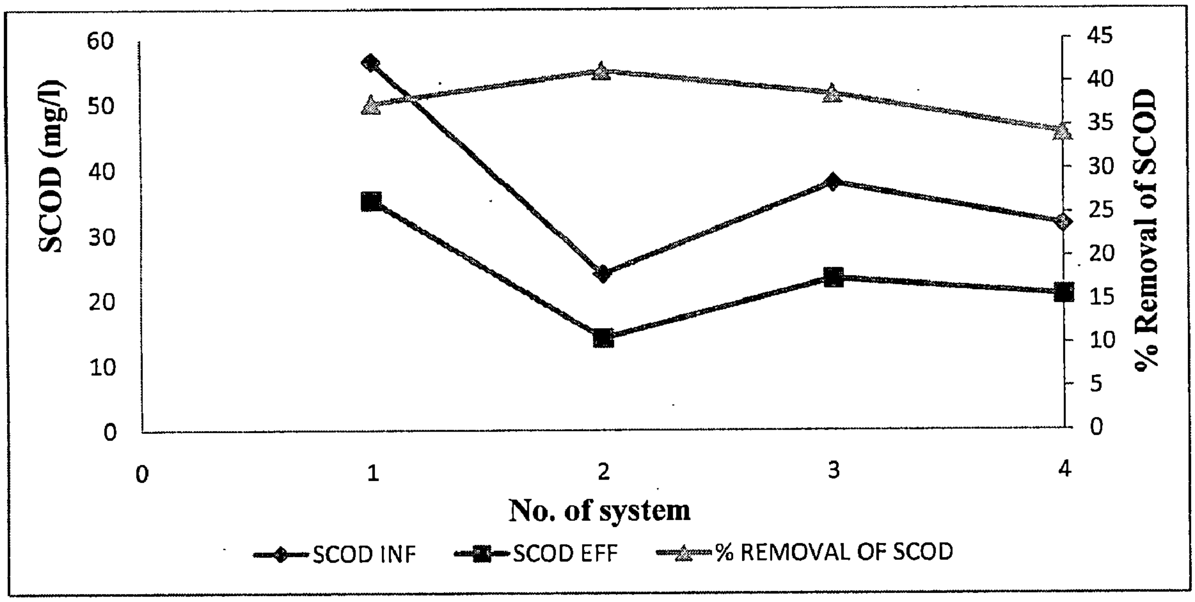

Figure 19: Variation in influent, effluent SCOD concentrations and % removal.

TSS: - TSS in influent and effluent of system during study was analyzed and the average values were 160.48 mg/l and 57.30 mg/l respectively, the mean percentage reduction of TSS was 64.15% (range 59.36%-68.96 %). The TSS values of the influent and effluent varied from 137.32 mg/l to 183.68 mg/l and 48.95 mg/l to 66.91 mg/l.

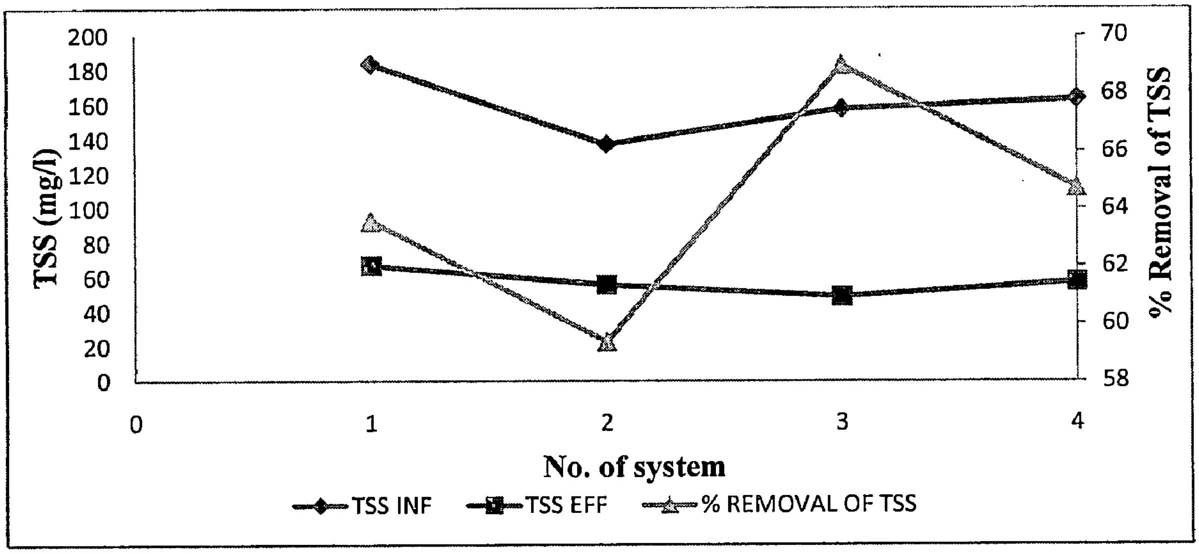

Figure 20: Variation in influent, effluent TSS concentration and % removal.

Ammonical Nitrogen Removal: - The performance of the treatment system with respect to ammonical nitrogen content is indicated in Figure 21. A 74.52% reduction was observed. The mean total ammonical nitrogen of influent was 26.68 mg/l (range 17.71 mg/l to 38.72 mg/l) whilst the mean total ammonical nitrogen of effluent was 6.38 mg/l (range 5.50 mg/l to 8.37 mg/l).

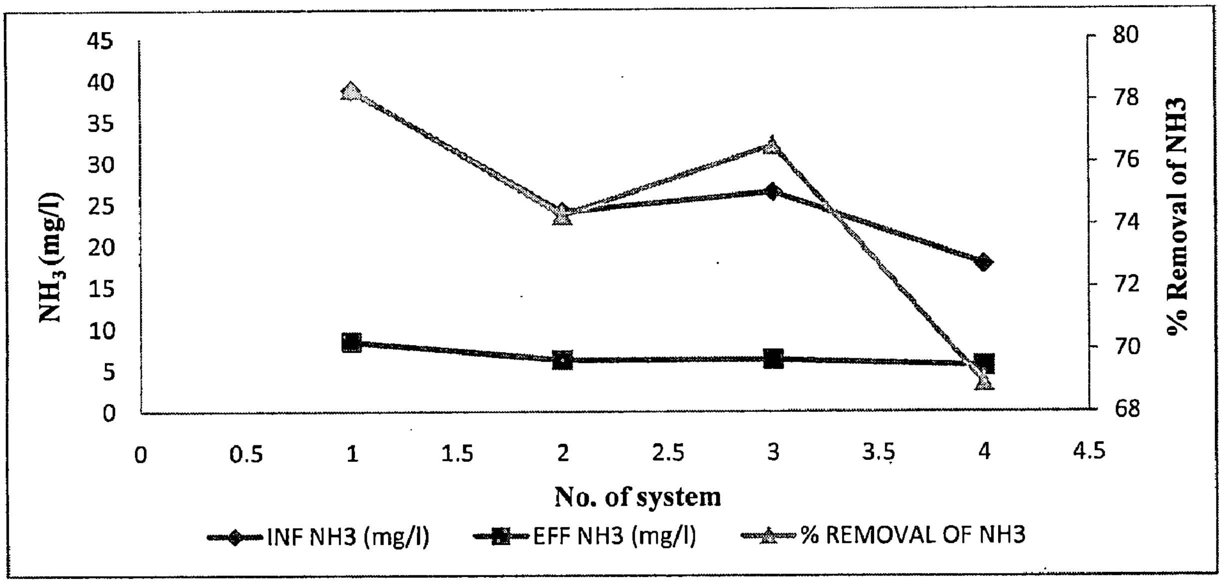

Figure 21: Temporal variation in Nitrogen species removal

Phosphorus Removal: - Mean phosphorus ion concentration of influent during the study period was 1.36 mg/l whilst that of effluent was 0.57 mg/l. Phosphorus ion concentration of influent varied from 0.96 mg/l to 1.86 mg/l. In effluent it varied from 0.32 mg/l to 0.91 mg/l. The removal of phosphorus by the system was 40.73%.

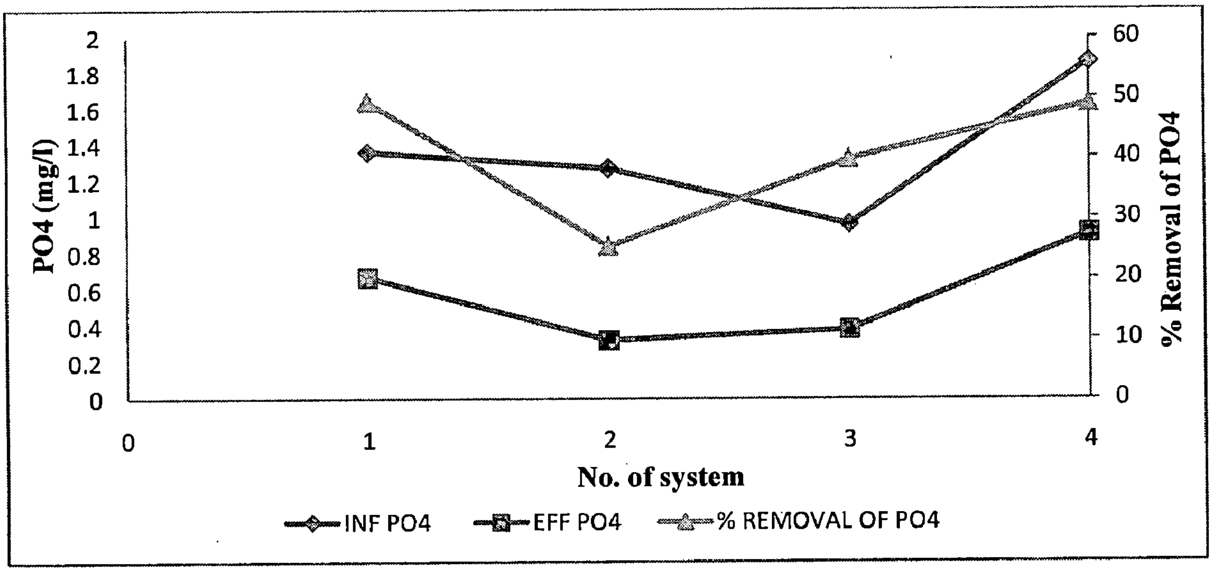

Figure 22: Variation in influent, effluent PO_4-P concentration.

CHAPTER- 3

3.1 CONCLUSIONS

This initial work has shown that the SBR is a system with high flexibility for treating the municipal wastewater and for different requirements (nitrogen or phosphorus) removal.

In chapter-1, anaerobic-aerobic pair is necessary to implement the biological phosphorus removal in a SBR process. After this, the sequenced anoxic-aerobic pair must be used for nitrogen removal. Instead of the strategies used for phosphorus removal, a low value of efficiency has been obtained.

The study clearly demonstrates that high removal of BOD, COD, NH_3, and TSS in sequencing batch reactor could be achieved in the range of 94.57, 92.12, 94.30 and 88.34% respectively in treating municipal wastewater.

In chapter-2, after all the facts presented in this chapter it is very hard to give the final conclusion or irrefutable stand about potential use of water hyacinth for wastewater treatment. This strategy can be tested in a small-scale, where water quality parameters should be measured at each level of treatment. After this feasibility study, assessment of suitability of this method for large-scale implementation should be made with a clear understanding of the physical, chemical and biological processes involved.

From the study it is evident that water hyacinth when grown over wastewater in open environment can efficiently clean up the wastewater, provide fresh water, and possibly clean up the air environment also by removing CO_2 and releasing O_2.

In this treatment, what is interesting is that these parameters have not shown an unusual increase in these samples of effluent, indicating that the treatment system has performed quite satisfactorily in keeping the pollutant levels down despite the high pollutant loads in influent. The system containing water hyacinth was found to perform well with regard to pH and DO levels. It also performed satisfactorily with regard to BOD and COD. Total suspended solids of effluent were high and the odour problem was not satisfactory. Based on the results, the treated healthy effluent may be used for agricultural or gardening purpose.

3.2 APPLICABILITY

Chapter-1

- The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flow rates. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration.

- As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal.

Chapter-2

In using the large-scale implementation of water hyacinth for wastewater treatment, a lot of question raises.

- Water hyacinth has great potential of treatment for wastewater but the first constrained to be noticed is it's incapability of adjusting to climatic conditions.

- What will be the affect on wastewater treatment when the water hyacinth covered partially or entire pond?

- The growth of water hyacinth is affected by the air movement, air temperature and relative humidity in natural conditions and this should be acceptable under the green house structure.

Another question: - Are described practicable of water hyacinth in tropics also it's practicable in regions where it could not be found in abundance?

Perhaps growing of water hyacinth in fish ponds where it would be use for water purification should also be avoided due to fast spreading it can cause anaerobic conditions in ponds which are not suitable for fish breeding. Aeration pumps should then be installed so the question is – Would it be economically justified to grow water hyacinth and fish in same ponds?

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