

Performance monitoring and Evaluation of Sewage Treatment Plant

A Dissertation

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Masters in Technology

in

Environmental Science and Technology

Submitted

By

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DECLARATION

I, the undersigned, hereby declare that the research work presented in the M.Tech project entitled "**Performance monitoring and Evaluation of sewage treatment plant**" has been carried out by me under the supervision and guidance of **Dr. A.S.Reddy, School of Energy and Environment, Thapar University, Patiala.**

Further, I declare that no part of this Dissertation has been submitted for a degree or any other qualification of any other university or examining body in India.



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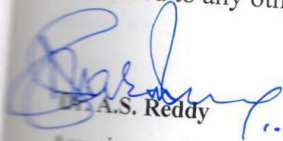
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CERTIFICATE

This is to certify that thesis entitled, "**Performance monitoring and Evaluation of sewage treatment plant**" submitted by **Ms. Sneha Gupta** in partial fulfilment of the requirements for the award of **Masters in Technology** Degree in **Environmental Science & Technology** at **Thapar University, Patiala** is an authentic work carried out by her under our supervision and guidance.

To the best of our knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.



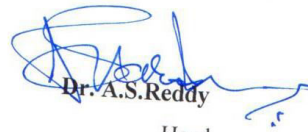
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ABSTRACT

The successive stages of the treatment at sewage treatment plant reduce the quantity of suspended solids, organic matter content, nutrient constituents, microbial load and bio-chemical oxygen demand of the sewage, so that the polluting strength of the final effluent becomes quite less as compared to the influent received. A performance efficiency investigation was conducted on the sewage treatment plant located at Thapar University campus which treats sewage through Up flow Anaerobic Sludge Blanket (UASB) reactor and facultative pond. Samples were taken from 4 stages of treatment over a period of six months and were subjected to microbiological and physio-chemical examination to find the reductions in the level of pollutants. The parameters studied are Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total phosphorous, total nitrogen, total suspended solids, MPN. The data gave a general picture of the extent to which treatment reduced the parameters at various treatment units of the plant. BOD, COD MPN and nutrients in the treated effluent were 21.51mg/L, 42.33 mg/L, 11.84 log units, 9.64 mg/L respectively. BOD removal efficiency of STP was 81.08%, COD removal efficiency was 83.6%, pathogen removal efficiency was 98.86% and nutrients removal efficiency was 51.73%.

Keywords: Up flow anaerobic sludge blanket, pathogen, BOD, COD, facultative pond.

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ABBREVIATIONS

STP:	Sewage treatment plant
UASB:	Up flow Anaerobic Sludge Blanket Reactor
HRT:	Hydraulic retention time
BOD:	Biochemical oxygen demand
COD:	Chemical oxygen demand
TSS:	Total suspended solids
DHS:	Down flow hanging sponge
RBC:	Rotating biological contractor
AFBR:	Anaerobic fluidized bed reactor
SRT:	Sludge retention time
OLR:	Organic loading rate
SBR:	Sequencing batch reactor
MPN:	Most probable number
DO:	Dissolved Oxygen
°C:	Degree Celsius

CHAPTER-1

INTRODUCTION

1.1 Background information

Environmental sanitation is of very important concern in the process of development of a country. Discharge of untreated sewage water is common a practice in many countries. This is common cause of pollution of surface and groundwater because of large gap between generation and treatment of wastewater. The wastewater discharged from residences, institutions and commercial establishments is termed as sewage or wastewater. Inadequate sanitation is one of the problems that the poor urban residents in the developing countries are facing (**Mesdaghinia et al., 2004**). Domestic and municipal wastewater is composed of 99.9% water and 0.1% suspended, colloidal and dissolved solids.

Due to the growing environmental pollution, there is a need to decontaminate the waste water and thus resulted in the study of characterization of the sewage water. Earlier, domestic sewage waste water treatment was limited upto the carbon removal only. But increasing population has lead to the development and implementation of new treatment technologies to remove other pollutants present in wastewater.

During the past two decades, several new sewage treatment technologies have been developed in many developing countries across the world. Some technologies are Fluidized Aerobic Bed (FAB), Sequencing Batch Reactor (SBR), UP flow Anaerobic Sludge Blanket Reactor (UASB) etc. Every technology has some useful and some harmful effects, therefore it should be applied in accordance to local conditions.

In many countries UASB has been applied for treating high strength waste water but in India it is applied for treatment of domestic waste water (**Lucas Seghezzo, 2000**). India is one of the leading countries in terms of the amount of sewage treated by UASB process (**Seto et al.; 2007**). It has been recognized as one of the most cost effective and suitable sewage treatment process considering the environmental requirements in India. At present about 23 sewage treatment plants are based on UASB technology for wastewater treatment.

Sewage treatment plant is a facility designed to receive wastewater from domestic, commercial and industrial sources and to remove materials that effect public health and safety when discharged into the environment. Sewage water is a complex matrix with many distinctive characteristics. These include high concentrations of BOD, COD, nutrients and pathogens. The characteristics and composition of domestic and industrial wastewater are different from each other (J.H.J. Ensink et al., 2007). Many physical, chemical and biological processes are used to remove various contaminants depending on its constituents (Zhang et al., 2010). Using advanced technology it is possible to re-use sewage treatment plant effluent for various purposes.

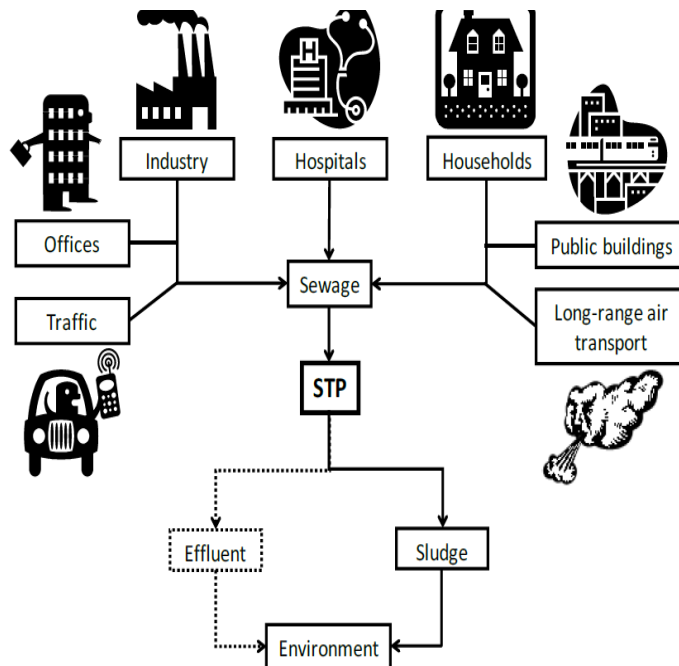


Fig 1.1 Schematic diagram of flow of substance to Sewage Treatment Plant (STP) and then into the environment.

(Source: Zitmer and Speece, 2000)

This M.Tech dissertation work is concerned with the performance evaluation of sewage treatment plant, based on Up flow Anaerobic Sludge Blanket Reactor and facultative pond, installed at Thapar University, Patiala, Punjab.

1.2 Importance of the work

Increasing scarcity of water in the world and rapid increase in population are the main reasons for the need of proper Water management systems. Sewage treatment is not cheap therefore the main problem in this is the implementation of low cost sewage treatment systems. Up flow Anaerobic Sludge Blanket reactor has been widely used to treat variety of wastewater all over the world. The water coming from this requires some post-treatments in order to meet the effluent standards. Secondary and tertiary treatment technologies are used for the removal of biodegradable organic matter, nutrients and pathogens. In this thesis performance evaluation of sewage treatment plant is carried out. Evaluation of reactor performance is extremely useful as it provides information on the treatment efficiency of the system and on how under load or overload the system is. The efficiency of the sewage treatment plants can be illustrated by a study on the evaluation of pollutants levels of the influent and effluent at the treatment plants discharging into the environment.

1.3 Objectives of study

1. To evaluate the overall performance of the Sewage Treatment Plant.
2. To evaluate the performance of UASB reactor.
3. To evaluate the performance of facultative pond.

1.4 Contents of the report

Present thesis work on performance of Sewage Treatment plant includes five chapters and a reference section.

Chapter-1 is “Introduction”. It provides brief background information, states objectives of the study, brings the importance of work.

Chapter-2 is “Literature Review”. This chapter presents the history of wastewater treatment, review on UASB reactor and Facultative pond. Their treatment process, efficiencies are discussed in this chapter.

Chapter-3 is “Materials and Methods”. This chapter identifies the work elements of the study and brings out the approach followed for carrying out the work on identified work elements.

Comprehensive details of the STP along with a schematic flow diagram are covered in this chapter.

Chapter-4 is “Results and Discussions”. Results of the study are covered in this chapter.

Chapter-5 is “Conclusion”. This chapter summarizes the outcome of the study and draws conclusion.

CHAPTER-2

LITERATURE REVIEW

2.1 History of waste water treatment

The treatment of wastewater is relatively a modern practice. In the past, people lived in relatively small population units, and the disposal of the waste was not a major problem but due to urbanization, the waste water treatment is becoming important in today's world (**Samuelsson, 2005**). Waste water is generally looked upon as a negative resource, because of its bad odour. The first sewer 'Great Sewer' was built in Rome in about 400 BC, a system mainly for transportation of drainage water. During the late 19th and the early 20th century, there was an awakening in development of waste water treatment systems, mainly in United Kingdom and United States. In addition to the collection and discharge of wastewater, physical, biological and chemical processes for waste water treatment were introduced for the removal of pollutants (**Britannica, 2012**). The function of waste water treatment plant is to speed up the natural cleansing process. Technically sound biological, physical, chemical and mechanical techniques are available today. As a result, public health and water quality are protected better today than ever before.

2.2 Waste water treatment

Sewage or waste water treatment is the process of removing contaminants from wastewater. It includes physical, chemical and biological processes to remove the contaminants. The objective of sewage treatment is to produce an environmentally safe effluent suitable for disposal or reuse. Sewage wastewater treatment includes 4 stages: preliminary treatment, primary treatment, secondary treatment, tertiary treatment. Many studies have shown that the utility of anaerobic processes as the core technology for sustainable wastewater treatment. They are responsible for the removal of large fraction of organic matter (**Foresti et al., 2006**).

Preliminary treatment: The aim of this treatment is to remove plastic, grease. Scum, solids and grit can block and wear valves, pumps, treatment equipments so they are removed by this treatment. Methods used to remove them may include physical, bar screens, grit chambers.

Preliminary treatment may also consist of a single process or a combination of processes such as coagulation, flocculation and floatation.

Primary treatment: In this treatment, sedimentation tank is used to screen out oils, greases and lighter solids. Sedimentation can remove all the settleable matter from the waste water and thus reduce the suspended solids (SS) and Biochemical Oxygen Demand (BOD) concentrations (**Davis 2011**). The floating materials are removed and the remaining liquid is subjected to secondary treatment.

Secondary treatment: In this treatment system fine suspended and dissolved degradable organic matter are removed by biological processes. The biological treatment processes can be classified as attached growth or suspended growth systems. Each system is dependent upon mixed populations of microorganisms in the presence of oxygen and nutrients.

Tertiary treatment: The main aim of tertiary treatment is to provide a final treatment to raise the effluent quality before it is discharged. This can be carried out by using physical separation of suspended solids from effluent or by biological processes. Other processes used are ozonation and ultraviolet (UV) radiation, which act to reduce level of pathogens in the effluent.

2.2 Up flow anaerobic sludge blanket (UASB) reactor

Several types of anaerobic digestion technologies exist for waste water treatment. Among these technologies, up flow anaerobic sludge blanket (UASB) reactors have achieved a considerable success and have been applied to treat a wide range of effluents such as sugar, pulp and paper, dairy, chemical, soft drinks and coffee processing industries (**Van Lier and Bonez, 2001**). Influent waste water enters the cylindrical reactor through an inlet at the bottom and flows upward through a blanket of biologically activated sludge, which is in the form of granular aggregates. The gases (methane and carbon dioxide) produced under anaerobic conditions cause internal mixing, which helps in the formation and maintenance of biological granules. At the top of reactor, the water and biogas reach an inverted cone gas-liquid –solid separation system. The biogas is collected in the inverted cone and the solids settle back in the reactor. The treated effluent is discharged and a portion of treated effluent is recycled back into the reactor to help in reactor mixing.

The process of granulation is affected by environmental and operational conditions in the reactor. According to various authors, granule composition strongly depends on the operational temperature (Tiwari et al., 2006). Sudden temperature changes could result in granule disintegration. Divalent ions such as Ca^{2+} and Fe^{2+} enhance the granulation. Preferred conditions for the granulation are high partial pressure of H_2 and neutral pH.

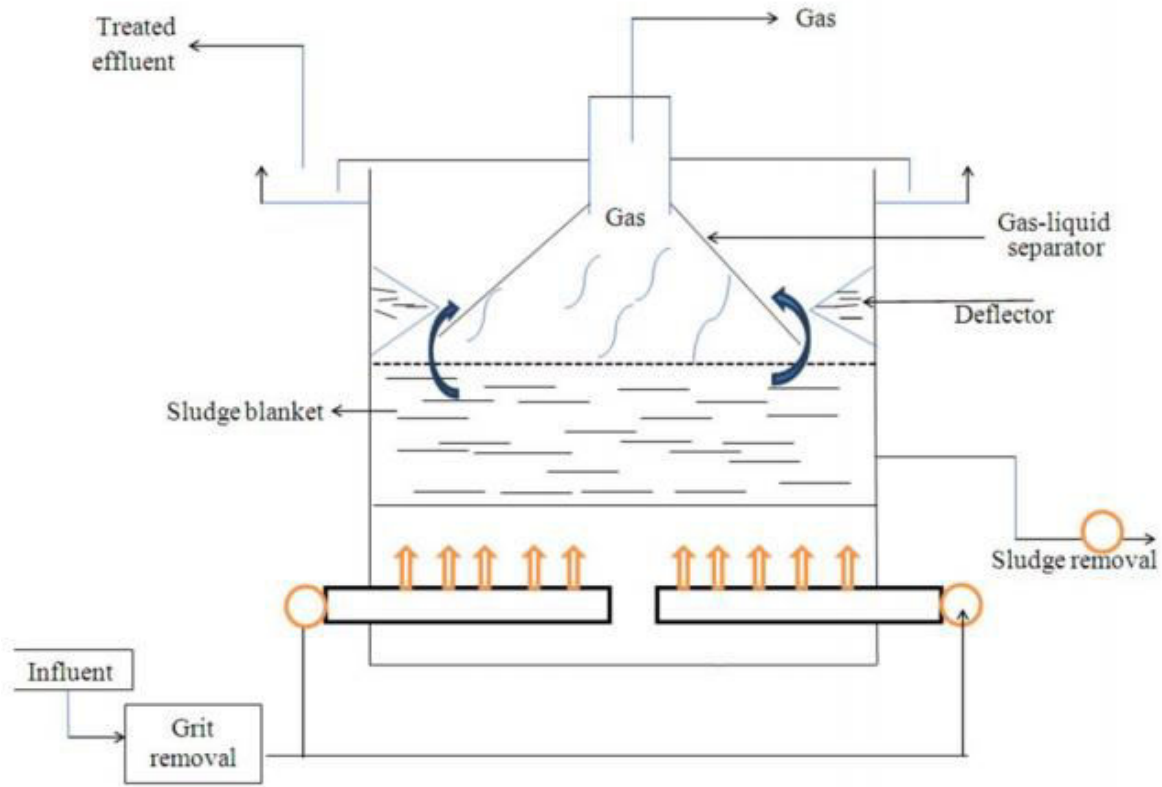


Fig 2.1 Schematic diagram of up flow anaerobic sludge blanket

2.1.1 Treatment of wastewater using Up flow Anaerobic Sludge Blanket Reactor (UASB)

Many studies were done on the feasibility of treating municipal waste water by UASB system under low temperature conditions. In one of the study, two reactors were started up at 20°C and then operated at various temperatures of 32, 20, 15, 11, 6° C and at several hydraulic retention times (HRT) varying from 48 to 3 hours during the period of 900 days (Singh K.S. et al., 2006). Chemical oxygen demand (COD) removal efficiency ranged from 70 to 90% upto an HRT of 6 hours and 11°C. Sulphate reduction played an important role in COD reduction. The study demonstrated that UASB system could be applied successfully for treatment of municipal

wastewater under low temperature conditions. The feasibility of grey water treatment in an UASB reactor was studied by (**Elmitwali and Otterpohl 2007**) which was operated at different hydraulic retention times of 16,10 and 6 hours and at a controlled temperature of 30°C. The results showed a total COD removal of 52-64% at HRT between 6 and 16 hours, 22-30% total nitrogen removal and 15-21% total phosphorous removal. Low temperature conditions and HRT also effect COD, BOD and SS removal. It was found that upto temperature of 11°C and HRT of 6 hours removal efficiency is good. When HRT was reduced to 4 hours or 3 hours, decrease in removal efficiency of COD and BOD was observed. Temperature did not affect SS removal efficiency (**Singh and Viraraghvan, 2003**). The treatment of domestic waste water using a laboratory scale hybrid Up flow Anaerobic Sludge Blanket (HUASB) reactor was studied. The reactor with volume of 5.9 liters and plastic cut rings as a packing media was operated at varying hydraulic retention times (HRT) for 110 days. The results showed that COD removal efficiency was in the range of 75-86% and BOD removal efficiency in the range of 70-91% (**J. R. Banu et al., 2007**). During the treatment, nutrients levels exhibited an increasing trend. It appears to be a promising alternative for treatment of domestic waste water in developing countries.

Two anaerobic pre-treatment technologies i.e. anaerobic fluidized bed reactor (AFBR) and UASB were compared and it was observed that both have similar performances with regard to chemical oxygen demand (COD) removal, suspended solids removal and gas generation. Much more efficient sludge stabilization was achieved in UASB reactors (**Motta et al., 2008**). Moreover UASB required lower energy for effluent recirculation than AFBR and thus it was concluded that UASB are more economical to operate. The advantages of combining anaerobic and aerobic processes was studied by (**Sperling et al, 2001**) and worked on pilot scale comprising of an UASB reactor followed by an activated sludge system. The plant was monitored and operated for 261 days. The plant showed good COD removal with efficiency of 69% to 84% for UASB reactor, 43% to 56% for activated sludge system and 85% to 93% for overall system. The final effluent suspended solids concentration was very low. The system showed better results at low hydraulic retention time i.e. 4 hours for UASB, 2.8 hours for aerobic reactor. It saves energy consumption and there is possibility of thickening and digesting the excess sludge in UASB reactor. The performance of UASB in combination with down flow hanging sponge (DHS) system at temperature of 15°C was studied for 6 months. The results showed that a combined system operated at HRT of 10.7 hours and total sludge retention time (SRT) of 88 days represented a cost effective sewage treatment process (**Machdar et al., 2000**).

It is most efficient combined process. It removed 90% total COD, 98% BOD₅, 94% TSS, 86% ammonia and 99.92% fecal coliform. Domestic sewage when treated in a combined Up flow Anaerobic Sludge Blanket Reactor and Rotating Biological Contactor concluded that an efficient pre-treatment of sewage implies reduction of organic loading rate applied to RBC and improved residual of total COD, ammonia in final effluent (**Tawfik et al., 2003**). The results supported the use of combined system UASB/RBC for treatment of domestic wastewater. Stillage wastewater treatment was carried out in full scale UASB reactors. Conventional parameters such as pH, temperature and efficiency of COD, BOD removal and organic loading rate, hydraulic retention time were investigated (**Mirsepasi et al., 2006**). The results showed that COD removal efficiency can be enhanced by enhancing organic loading rates and up flow velocity, by decreasing hydraulic retention time. The hydraulic and kinetic factors also affect the performance of the system in the process of developing compact treatment system. Domestic wastewaters can be anaerobically treated in Mesophilic UASB reactor with 70% COD removal efficiency without any chemical treatment (**Seghezzo L., 2004**). The effluent suspended solid concentrations were very low and the results obtained perfectly fit the second order multiple substrate kinetic model at steady state operating conditions. The influence of excess sludge produced in Trickling filter on the performance of a UASB reactor used for combined treatment of domestic wastewater and trickling filter sludge was studied (**Pontes and chernicharo et al., 2003**). It was found that the return of excess aerobic sludge produced in trickling filter has not affected the performance of UASB reactor and final quality of effluent was better.

2.3.2 Parameters affecting the efficiency of a UASB Reactor

The efficiency of a UASB reactor is affected by several conditions which includes temperature, pH, hydraulic retention time (HRT), organic loading rate (OLR), up flow velocity, type of sludge and sludge age (**Wiegant, 2001**).

2.3.2.1 Effect of temperature

The temperature influences the growth and survival of microorganisms. Three ranges of temperature for treatment of effluent are psychrophilic, mesophilic and thermophilic (**Madigan et al., 1997**). It is observed that the reduction in operational temperature leads to significant decrease in the maximum growth and substrate utilization rates (**Lettinga et al., 2001**). A 33% drop in the soluble COD removal efficiency was reported when temperature was reduced below 10°C. **Singh et al., (1996)** treated municipal wastewater using UASB system under low

temperature conditions and observed 70% COD removal at 11°C and 30 to 50% at 6°C. 82% COD removal at 28°C, 72% at 20°C, 68% at 14°C and 38% at 10°C was reported by (Lew et al., 2003). There was an increase in methane production with the increase in the temperature. Halasheh (2002) treated high strength sewage of COD = 1531 mg/L using pilot plant UASB reactor. The COD removal efficiencies reported were 62% and 51% at ambient temperature of 18-25°C.

2.3.2.2 Effect of pH

The pH is extremely important and it should be maintained in the desired range. In the case of domestic sewage, pH is maintained in range of 6-7.2 (Van Haandel, 1994). The UASB reactors are extremely stable in terms of pH and buffering capacity (Leitao, 2004). For treating kitchen wastewater pH 7 provided an optimal working environment resulting in 86% TOC removal and 82% COD removal (Zhang et al., 2005).

2.3.2.3 Effect of hydraulic retention time (HRT) and up flow velocity

The HRT is one of the important parameters affecting the performance of a UASB reactor. The up flow velocity is directly related with HRT and plays an important role to entrap suspended solids. The COD removal efficiency of UASB reactor also decreases at elevated up flow velocity because higher up flow velocity reduces the contact time between sludge and wastewater (Mehmoud, 2002). There is no effect of HRT on treatment efficiency when reactor is operated at HRT in the range 4.4-14.5 hours with up flow velocity varying between 0.4 and 1.3 m/hr (Vieira and Garcia, 1992). Too short HRT causes rapid decline in the performance of a UASB reactor (Ragen et al., 2001). 93% SS and 60% COD removal efficiency of a UASB reactor at HRT of 6 hours was reported by Leitao (2004). Below this, efficiency dropped significantly and SS removal efficiency of reactor was almost negligible at HRT of 1 hour. Tronovec and Britz (1998) treated food industry wastewater by using UASB reactor and reported COD removal efficiency of reactor more than 90% at HRT of 10 hours.

2.3.2.4 Effect of organic loading rate (OLR)

The organic loading rate can be changed by varying COD concentration of influent, flow rate, HRT and volume of the reactor.

$$\text{OLR} = \frac{Q \times \text{COD}}{V}$$

$$= \frac{\text{COD}}{\text{HRT}} \dots\dots\dots (2.1)$$

Where

OLR = Organic loading rate (kg COD/m³.day)

COD = Chemical oxygen demand of influent (kg COD/m³)

Q = flow rate (m³/ day)

V = reactor volume (m³)

HRT = Hydraulic retention time (days)

Some researchers reported an increase in the efficiency of the UASB reactors with increasing organic loading rate (**Brown, 1998**). In case of effluent having COD contents lower than 300 mg/L, the efficiency of UASB reactor was low. They showed maximum COD removal efficiency of 60% when COD concentration was higher than 300 mg/L. A further decrease in SS removal efficiency was observed with an increase in OLR (**Ruiz et al., 1997**).

2.3.3 UASB Reactor efficiencies

Efficiencies of UASB reactors are estimated by means of empirical relations. The COD and BOD removal efficiencies are affected by hydraulic retention time of the system, ranging from 40 to 70% for COD removal and 45-90% for BOD removal (**Batstone et al., 2002**).

$$E_{\text{COD}} = 100 \times (1 - 0.68 \times t^{-0.35}) \dots\dots\dots (2.2)$$

Where

E_{COD} = Efficiency of UASB reactor in terms of COD removal (%)

t = Hydraulic retention time (days)

0.68 = Empirical constant

0.35 = Empirical constant

$$E_{\text{BOD}} = 100 \times (1 - 0.70 \times t^{-0.50}) \dots\dots\dots (2.3)$$

Where

E_{BOD} = Efficiency of the UASB reactor of BOD removal (%)

t = Hydraulic retention time (hours)

0.70 = Empirical constant

0.50= Empirical constant

2.4 Facultative pond

Facultative ponds are either primary facultative ponds that receive raw wastewater or secondary facultative ponds that receive settled wastewater effluent from anaerobic ponds. They are designed for BOD removal on the basis of relatively low surface loading (100-400 kg BOD/ha d) at temperature between 20-25°C. Anaerobic ponds hardly produce effluents that comply with usual discharge standards established by environmental agencies. Taking into account the limitations associated with the anaerobic systems and the need to develop technologies that are more appropriate for the developing countries, it is important to include a post-treatment stage for effluents generated in anaerobic reactors. The main role of the post treatment is to complete the removal of organic matter as well as to remove constituents such as nutrients (N and P) and pathogenic organisms.

Facultative ponds are largely used for post treatment of effluents from anaerobic ponds. They are usually 1-2 m deep and are geometrically designed to have high length to width ratio upto 10:1 to stimulate a plug flow regime (Mara et al., 1992). When an effective anaerobic pre-treatment is applied before the sewage discharge into the pond, the concentrations of organic matter and suspended solids are largely reduced. In these conditions, the limiting factor that determines the minimum retention time, will usually be the removal of pathogenic organisms and not the stabilization of organic matter (Cavalcanti, 2003). They are designed for BOD removal on the basis of low surface loading (100-400kg BOD/hr.d) to permit the development of a healthy algal population as the oxygen for BOD removal is generated by algal photosynthesis (Mara and Pearson, 1986). Photosynthetic activity of algae results in variation of dissolved oxygen concentration and pH. DO concentrations can rise to more than 20 mg/l and pH to more than 9.4. Ammonia and sulphite toxicity is pH-dependent. As the pH of facultative pond increases, the unionized form of ammonia increases while sulphide production decreases. In facultative ponds BOD removal of about 70% on an unfiltered basis and more than 90% on filtered basis can be achieved.

2.4.1 Treatment of wastewater using Facultative pond

A domestic sewage treatment system comprised of a UASB reactor followed by facultative pond, operated with very low detention times (1.4-2.5 days in each pond), was able to achieve excellent

results for BOD removal, ammonia removal (**Mascarenhas, 2004**). The average concentrations observed in the final effluent were 44 mg BOD/L and 7.3 mg NH₄-N/L. **Von Sperling et al., (2002)** studied on the removal efficiency of pathogens in a combined UASB reactor and facultative pond system. UASB reactor is a partitioned reactor, consisting of three compartments, three gas separation devices and single settler compartment for solids separation (**Chernicharo and Cardoso, 1999**). The UASB reactor-pond system showed very good pathogen removal efficiencies. The reactor removed 1 log unit of pathogens, pond showed removal efficiencies varying from 1 to 4 log units. The best operating conditions were with an average HRT of about 9 days in each pond. Facultative ponds play an important role in pathogen removal. Primary facultative ponds achieved 88-98% of pathogen removal. Pathogen free effluents were produced by primary facultative pond with the retention time of 18.9 days and by secondary facultative pond with retention time of 6.8 days (**Mara et al., 1999**). The hydraulic behavior of stabilization ponds were studied using a stimulus response technique. The resulting time were used to calculate the mean hydraulic resistance time. The percentage of dead volume ranged from 10 to 42% (**Maria D., 1990**). The statistical analysis of the results indicates that the completely stirred tank reactor model can be used to represent the hydraulic behavior of all ponds at a 99% confidence level.

2.4.2 Facultative Pond efficiencies

The design of facultative ponds focuses on BOD removal. The design of ponds is based on rational and empirical approaches. The empirical design is based on correlating performance data. The rational design approach models the ponds performance by using kinetic theories of biochemical reactions in association with the hydraulic flow regime.

2.4.2.1 Pathogen Removal

It can be estimated by using following equation:

$$\frac{N_e}{N_o} = \frac{1}{(1 + k_{b(T)} \theta)} \quad \dots\dots (2.4)$$

Where:

N_o = pathogen concentration in influent (org/100ml)

N_e = pathogen concentration in effluent (org/100ml)

θ = Hydraulic retention time

$k_{b(T)}$ = pathogen coefficient

$$k_{b(T)} = k_{b20} \theta^{(T-20)} \dots\dots (2.5)$$

Where:

k_{b20} = pathogen coefficient at 20°C, taken as 2.6.

θ = temperature coefficient, taken as 1.19.

2.4.2.2 Ammonical Nitrogen removal

Expected ammonical nitrogen removal can be calculated using following equations:

When temperature is below 20°C

$$C_e = \frac{C_o}{1 + [(A/Q) (0.0038 + 0.000134 T) \exp \{(1.041 + 0.044T) (pH - 6.6)\}]} \dots\dots(2.6)$$

When temperature is more than 20°C

$$C_e = \frac{C_o}{1 + [5.035 \times 10^{-3} A/Q \exp \{1.54 (pH - 6.6)\}]} \dots (2.7)$$

Where:

C_e = Ammonical nitrogen concentration in effluent pond (mg N/L)

C_o = Ammonical nitrogen concentration in influent pond (mg N/L)

A = pond surface area (m²)

Q = wastewater flow rate (m³/d)

T = temperature (°C)

pH = 7.3 exp (0.0005A_i)

A_i = influent alkalinity (mg CaCO₃/L)

2.4.2.3 Total nitrogen removal

For estimating total nitrogen removal following equation is used in case of facultative pond:

$$C_e = C_o \exp [-\{0.0064 \times (1.039)^{T-20}\} \{\theta + 60.6 (\text{pH}-6.6)\}] \quad \dots\dots (2.8)$$

Where:

C_e = Ammonical nitrogen concentration in effluent pond (mg N/L)

C_o = Ammonical nitrogen concentration in influent pond (mg N/L)

T = temperature ($^{\circ}\text{C}$)

pH = $7.3 \exp (0.0005A_i)$

A_i = influent alkalinity (mg CaCO_3/L)

CHAPTER-3

MATERIALS AND METHODS

3.1 Introduction

In this chapter the methods followed for the study are discussed. For achieving the objectives, the study work was planned as follows:

- Monitoring and Characterization of waste-water of STP
- Performance evaluation

3.2 Monitoring and Characterization of waste water of STP

For monitoring the STP, sampling locations were identified and the parameters for which samples should be analyzed were decided. Monitoring involves collection of samples on the monthly basis for 6 months. For MPN, the sample was collected in the sterilized autoclaved bottles free from contamination. The collected samples were brought to laboratory immediately and were analyzed for various parameters and the samples were preserved until the analysis was over. The various parameters analyzed are discussed in table 3.1.

The samples were collected from:

- Inlet of STP
- Outlet of Baffled Anaerobic Reactor
- Outlet of Facultative pond
- Treated Effluent tank

3.3 Analytical techniques

The physio-chemical characteristics of the influent, effluent are determined as per standards methods, APHA, 1999.

Table 3.1: Analytical techniques for testing of waste water parameters

Sr. No.	Parameter	Method	Reference
1.	pH	Electrometric Method	APHA (1999) “Manual Standard Method”
2.	Dissolved Oxygen	Winkler’s Method	APHA (1999) “Manual Standard Method”
3.	Biochemical Oxygen Demand (BOD)	5-day BOD test	APHA (1999) “Manual Standard Method”
4.	Chemical Oxygen Demand (COD)	Closed Reflux Method	APHA (1999) “Manual Standard Method”
5.	Ammonical Nitrogen	Preliminary distillation method followed by titrimetric method	APHA (1999) “Manual Standard Method”
6.	Organic Nitrogen	Macro-Kjeldahl Method	APHA (1999) “Manual Standard Method”
7.	Total Phosphorous	Stannous Chloride Method (UV spectrophotometer)	APHA (1999) “Manual Standard Method”
8.	Sulphates	Turbidimetric Method (Turbidity meter)	APHA (1999) “Manual Standard Method”
9.	Sulphides	Iodometric Method	APHA (1999) “Manual Standard Method”
10.	Most Probable Number (MPN)	Serial Dilution Method	APHA (1999) “Manual Standard Method”

3.4 Performance evaluation

Using the monitoring data both at whole plant level and at the individual treatment unit level, performance evaluation of STP was done. Performance evaluation was done for the removal of pollutants from the wastewater. By knowing the inlet and outlet concentrations of different parameters, plant removal efficiencies for various parameters were calculated.

3.5 Sewage treatment plant studied

1 MLD capacity sewage treatment plant situated in north-west corner of the Thapar campus, Patiala, Punjab was studied. Schematic diagram of STP is given in figure 3.1. The sewage treatment plant included the following units:

- Bar screen chambers
- Raw sewage sump
- Raw sewage pumps
- Baffled Anaerobic Reactor
- Facultative pond
- Multistage Filters
- Treated effluent tank

In sewage treatment plant, raw sewage is collected from all residential areas, laboratories under gravity into the underground raw sewage sump after passing it through the bar screens. The bar screens, through removing coarse solids from the sewage, helps in protecting the raw sewage pumps. The raw sewage sump helps in holding the incoming sewage, facilitates both pumping of sewage through the STP and dampening the flow variations in the received sewage. With the help of raw sewage pumps, the sewage collected in the sump is pumped and passed through the STP. The pumped raw sewage is passed through a distribution box and loaded as four equal streams into the two-stage Baffled Anaerobic Reactor (BAR) for the removal and stabilization of the suspended solids. BOD of the sewage is removed in this reactor. Even a significant amount of colloidal organic matter of sewage is anaerobically bio-oxidized in this reactor. TKN (ammonical and organic nitrogen) and pathogen are also significantly removed. From here the treated effluent is allowed to flow into facultative pond with diffused aeration zones for further treatment i.e. removal of BOD, COD, nutrients and pathogen removal. Use of diffused aeration systems enhance pond's capacity to remove loaded BOD. The facultative pond removes BOD to less than 20 mg/L level. But the escape of the algal cells into the effluent results in significant compromise on BOD removal efficiency. The treated effluent coming out from the facultative pond is passed through 4-stage multistage roughing filters for removing the washed out algal cells and other suspended solids. The treated effluent coming out of multistage roughing filters is further pumped and reused within the campus for irrigation purposes. Excess of the effluent is allowed to overflow into the recharge well for disposal into the groundwater. The grit and sludge

dredged out from raw sewage sump and the sludge wasted from baffled anaerobic reactor is collected into the sludge thickening and stabilization pit. Clear supernatant of the pit is allowed to flow back under gravity into the raw sewage sump for treatment along with the raw sewage.

Bar screen chamber

Bar screen chamber is the first unit of the STP. Sewer bringing the raw sewage opens into a rectangular channel provided at the bottom of bar screen chamber. Bars of the screen are provided in such a way that they are inclined from the front and completely covering the channel from the top on the downstream side. Therefore no sewage can enter the downstream unit without being screened.

Raw sewage sump and raw sewage pumps

The raw sewage sump is having 50 m³ sewage storing capacity. The dimensions of sump are 5m long, 5m wide and 2m liquid depth. The central suction pit is 1.2 m top diameter and 0.3 m deep. Three pumps each of 1.5 times the average flow (62.5 m³/hour) pumping capacity, are used for pumping the sewage from the sump to the baffled anaerobic reactor. The pumps are connected to an emergency supply source to ensure that the pumping of sewage from the sump and loading to baffled anaerobic reactor is not affected.



Fig 3.1 Raw sewage sump and raw sewage pumps

Baffled Anaerobic Reactor

Two-stage Baffled Anaerobic Reactor with 4 m liquid depth and 0.6 m depth (above the liquid) is used for the sewage treatment. The pumped raw sewage is passed through a distribution box for dividing the flow into four equal streams. The distribution box is a circular chamber. Raw sewage enters the distribution box from the bottom at the centre. Four equal effluent streams emerge from the periphery from the four sides. The four streams emerging from the distribution box are loaded into the four units of stage-1 and stage-2 BAR through four distribution tubes. The distribution tubes are 200 mm internal diameter and each has 100 mm size nozzle at discharge end. Each distribution tube has a horizontal tube portion and vertical tube portion through a T-joint. The vertical tube is of 200 mm internal diameter has a 100 mm diameter nozzle at the bottom.

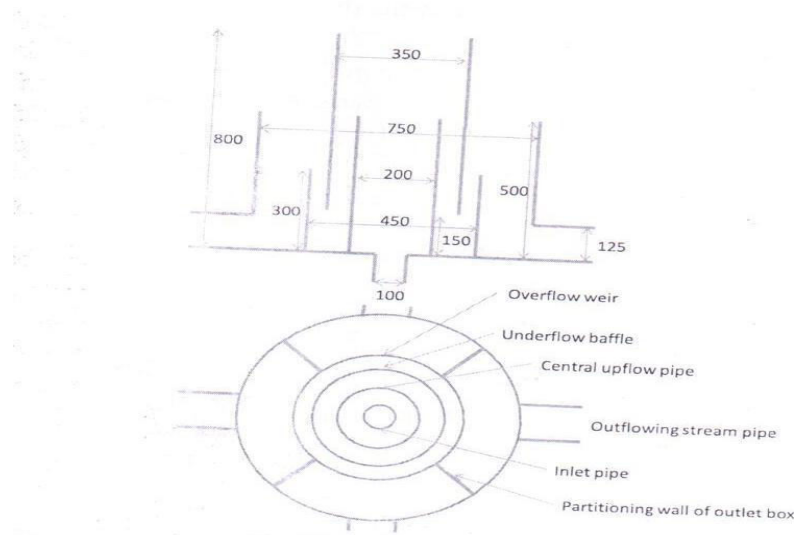


Fig 3.2 Flow distribution box

Facultative Pond

The facultative pond is 1.5 m deep and is having 0.3 m free board. Surface area of the pond is 1050 m². A pond of 35 m length and 30 m width is divided into 10 m wide facultative pond by two baffles. The pond include two diffused aeration zones, each of 22 m top length and 12 m top width and 10 m bottom length and 2 m bottom width. In these zones the liquid depth may vary from 1.5 m to 3.5 m. The system include two blowers each capable of delivering 100 Nm³/hr of air at around 0.45 to 0.5 kg/cm² pressure. The air is supplied to both the diffused aeration zones

and delivered into effluent through 10 diffusers each. Purpose of this is to ensure better and higher rates of surface re-aeration during nights when algae instead of contributing, consumes oxygen from the pond water. Diffused air also supplies some oxygen to the pond. Due to this aerobic conditions are improved and expecting healthy algal growth and more oxygen supply during daytime. All these facilities enhance surface loading of organic matter to the pond.



Fig 3.3 Facultative pond

Multistage Roughing Filters

Effluent from facultative pond is passed through multistage roughing filters in order to remove suspended solids including algal cells. It also results in the denitrification removal of nitrate nitrogen, removal of soluble BOD and reduction in coliform count. The multistage filters have four stages and the waste water flows upwards through the filter beds in each stage. Each filter is 4m long and 4m wide square shaped cell and has a hopper bottom. Each stage has 1.2 m thick graded gravel layer, a bottom sludge storage space and a top filtered water storage reservoir. A drain of 125 mm internal diameter with regulatory valve will be provided at the bottom of each stage for facilitating draining out of backwash water. The drained out backwash water is conveyed through common drain of 150 mm internal diameter into the raw sewage sump of STP. A central vertical inlet pipe, capped at the top and connected to the outlet of the previous unit and is used to deliver the influent wastewater below the graded gravel bed layer. The first stage of the filter receives wastewater from outlet of facultative pond. From the last stage, filtered water is discharged into treated effluent pond through an outlet pipe. Inlets of all four stages have

regulatory valves for stopping effluent flow during backwashing. Wastewater when filtered through the graded gravel beds, suspended solids get removed and accumulate in the bottom hopper portion of the filter stages as sludge.



Fig 3.4: Multistage roughing filters

Treated effluent sump

This sump receives the effluent after treatment from multistage roughing filters. The sump is 4m long, 4m wide and 2.6 m deep. The treated effluent sump is provided with an overflow drain at 1.6 m height from the bottom. 250 mm internal diameter pipeline is used for carrying the treated effluent.

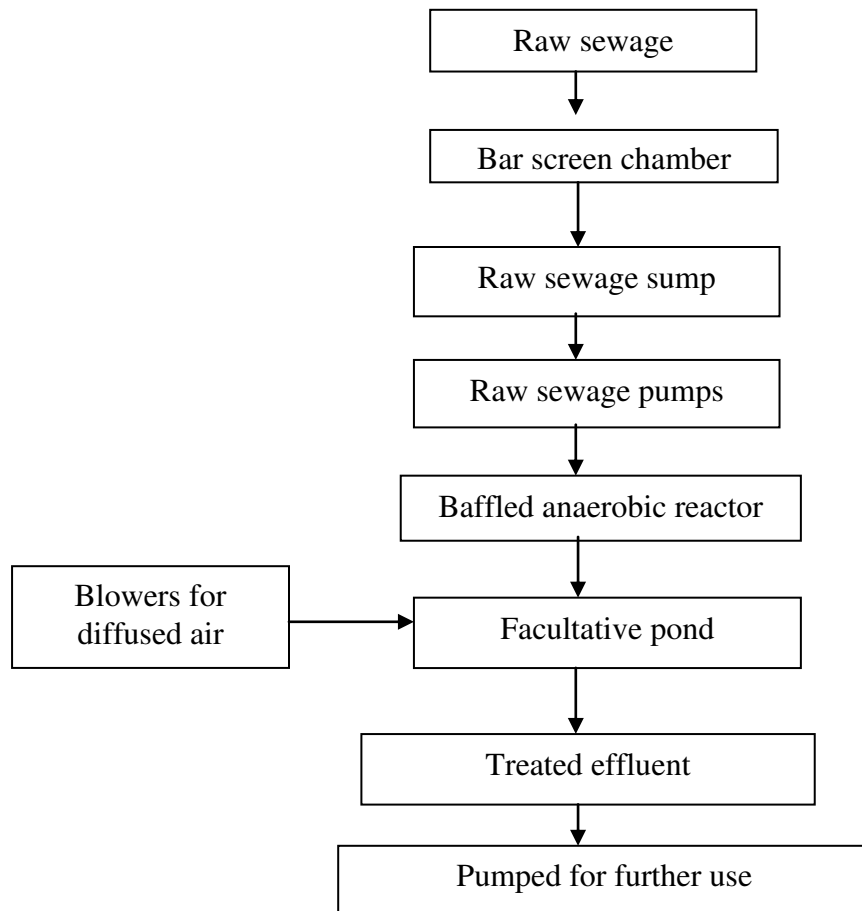


Fig 3.5: Schematic process flow diagram of sewage treatment plant

Table 3.2: Dimensional details of various units of Sewage treatment plant (STP)

Units	Dimensions
Bar screen chamber and bar screen	Having 1.1m width, 2.7m length, 10mm spacing between the bars
Raw sewage sump	Single sump 5m long and 5m wide
Raw sewage pumps	3 pumps of 62.5 m ³ / hour pumping capacity
Baffled anaerobic reactor	4 distribution lines , 20m long, 5m wide
Facultative pond	Having 105m length,10m width, 0.5m free board

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Introduction

Results obtained from the treatment process monitoring, overall performance evaluation of the STP at Thapar University, Punjab are presented and discussed in this chapter. The performance analysis data obtained from the monitoring of the STP at four different locations i.e. inlet, outlet of Baffled anaerobic reactor, outlet of facultative pond, treated effluent of the STP for over 6 months period are discussed. The STP is designed and operated mainly for the removal or reduction of TSS, BOD, COD and pathogen from the raw sewage. The performance of every unit of STP is given in table 4.1- 4.4 and overall removal efficiency is given in table 4.5.

4.2 Performance evaluation

4.2.1 Overall Performance analysis of STP

STP at Thapar University includes a UASB reactor and a facultative pond for treatment of the sewage wastewater. The STP was designed to treat 1 MLD. The STP is supposed to treat the waste water to comply with the applicable effluent standards of BOD: 10 mg/l, COD: 60 mg/l and pathogens less than 1000/100 ml. For nutrients removal, less than 10mg/l for nitrogen and less than 2 mg/l for phosphorous are required.

Performance of the STP was evaluated in terms of BOD, COD removal. Average BOD removal efficiency of STP is 75.61% and of treated effluent is 25.24 mg/L. Average COD removal efficiency is 81.62% and of treated effluent is 38 mg/L. BOD and COD removal efficiencies of the STP are quite satisfactory. This can be due to presence of high algal concentrations. Observations on nutrient removal efficiencies are variable. Organic nitrogen removal was very low (around 35%). Low ammonical nitrogen removal efficiencies are common with UASB reactors and facultative pond because nitrification and denitrification processes are very insignificant.

Table 4.1: Performance of inlet of STP

Parameters	1st	2nd	3rd	4th	5th	6th	Mean	Standard Deviation
Temperature (°C)	30.8	28.4	29.3	30.1	25.2	23.1	27.81	3.02
BOD(mg/l)	114	112.5	140	115	100	110	115.25	13.28
COD (mg/l)	216	336	288	304	240	210	265.66	51.26
Total-P(mg/l)	2.4	1.8	2.6	2.8	2.16	2.54	2.38	0.35
Ammonical-N (mg/l)	15.4	18.48	20.44	21.84	23.52	19.78	19.91	2.80
Organic-N (mg/l)	0.224	0.6	0.39	0.67	0.24	0.46	0.43	0.18
Total-N(mg/l)	15.62	19.08	20.83	22.51	23.76	20.24	20.34	2.84
MPN (log)	16.2	16.45	16.6	16	16.9	16.3	16.40	0.32
Sulphates (mg/l)	3.41	4.6	4.5	3.1	4.16	4.26	4.01	0.61
Sulphides (mg/l)	1.6	2.4	2	1.8	2.1	1.9	1.96	0.27

Table 4.2: Performance of Baffled Anaerobic Reactor of STP

Parameters	1st	2nd	3rd	4th	5th	6th	Mean	Standard Deviation
Temperature (°C)	29.1	27.5	28.1	29.3	24	22.5	26.75	2.82
BOD(mg/l)	82.5	85	72	93	74	80	81.08	7.65
COD (mg/l)	184	192	176	192	160	140	174	20.51
Total-P(mg/l)	1.6	1.4	2	2.1	2.09	1.64	1.80	0.29
Ammonical-N (mg/l)	12.32	15.96	17.92	18.2	16.13	12.44	15.49	2.57
Organic-N (mg/l)	0.16	0.28	0.16	0.44	0.11	0.2	0.229	0.12
Total-N(mg/l)	12.48	16.24	18.08	18.64	16.24	12.64	15.72	2.63
MPN (log)	15.4	15	15	14.34	14.13	15.4	14.87	0.53
Sulphates (mg/l)	2.41	2.5	2.3	2.3	2.91	2.65	2.51	0.23
Sulphides (mg/l)	1.2	1.6	1.2	2	1.9	1.1	1.5	0.38

Table 4.3: Performance of Facultative Pond of STP

Parameters	1 st	2 nd	3 rd	4 th	5 th	6 th	Mean	Standard Deviation
Temperature (°C)	28.3	26.5	28	28.4	23.2	21.7	26.01	2.88
BOD(mg/l)	47.1	53.25	60	58	42	43.15	50.58	7.64
COD (mg/l)	112	128	128	96	80	100	107.33	19.00
Total-P(mg/l)	1.2	1.1	1.4	1.3	1.9	1.5	1.4	0.28
Ammonical-N (mg/l)	10.08	13.72	14.84	15.12	12.15	8.12	12.33	2.78
Organic-N (mg/l)	0.11	0.16	0.05	0.28	0.1	0.12	0.14	0.07
Total-N(mg/l)	10.19	13.88	14.89	15.4	12.25	8.24	12.47	2.81
MPN (log)	13.57	13.45	13.1	13.57	12.46	14.6	13.45	0.70
Sulphates (mg/l)	1.99	2.1	2	1.6	2.2	2.12	2.00	0.21
Sulphides (mg/l)	1.8	1.2	2.2	2.6	1.6	0.9	1.71	0.62

Table 4.4: Performance of Treated Effluent of STP

Parameters	1 st	2 nd	3 rd	4 th	5 th	6 th	Mean	Standard Deviation
Temperature (°C)	27.9	26	27.6	27.1	22.7	20.5	25.3	3.01
BOD(mg/l)	17.6	24.75	22	17.5	23	24.23	21.51	3.21
COD (mg/l)	48	48	32	48	40	38	42.33	6.74
Total-P(mg/l)	0.8	0.5	1.1	0.6	0.2	0.42	0.60	0.31
Ammonical-N (mg/l)	9.24	11.2	13.16	12.04	7.54	4.2	9.56	3.30
Organic-N (mg/l)	0.05	0.051	0.11	0.16	0.06	0.04	0.08	0.04
Total-N(mg/l)	9.29	11.25	13.27	12.21	7.60	4.24	9.64	3.34
MPN (log)	12.04	11.6	12.7	11.15	11.2	12.37	11.84	0.63
Sulphates (mg/l)	1.7	1.3	1.1	1.1	1.5	1.2	1.31	0.24
Sulphides (mg/l)	1	0.6	1.4	1.2	1.2	0.4	0.96	0.38

Table 4.5 Overall removal efficiencies of STP during 6 months

Removal Efficiencies (%)								
Parameters	1 st	2 nd	3 rd	4 th	5 th	6 th	Mean	Standard Deviation
BOD(mg/l)	84.5	78.2	84.2	84.7	77	77.9	81.08	3.73
COD (mg/l)	77.7	85.7	88.8	84.2	83.3	81.9	83.6	3.95
Total-P(mg/l)	66.6	72.2	57.6	78.5	75.9	83.4	72.36	9.19
Ammonical-N (mg/l)	40	39.3	35.6	44.8	64.7	78.7	50.516	17.24
Organic-N (mg/l)	75	90.6	71.4	75	72	83.2	77.86	7.526
Total-N (mg/l)	40.5	41	36.2	45.7	67.98	79	51.73	17.47
MPN (log)	99	99.2	97.9	99.5	99.6	98	98.86	0.742
Sulphates (mg/l)	50.1	71.7	75.5	64.5	63.9	71.8	66.25	9.11
Sulphides (mg/l)	37.5	62	30	33.3	42.8	70.5	46.016	16.46

Table 4.6 Average performance of STP

Parameter	Concentration (mg/L)			
	Inlet	Baffled Anaerobic Reactor	Facultative Pond	Outlet
BOD(mg/l)	115.25/13.28	81.08/7.65	50.58/7.64	21.51/3.21
COD (mg/l)	265.66/51.26	174/20.51	107.33/19	42.33/6.74
Total-P (mg/l)	2.38/0.35	1.80/0.29	1.4/0.28	0.60/0.31
Ammonical-N (mg/l)	19.91/2.808	15.49/2.57	12.33/2.786	9.56/3.30
Organic-N(mg/l)	0.43/0.183	0.12/0.22	0.13/0.07	0.08/0.04
Total-N(mg/l)	20.34/2.84	15.72/2.63	12.47/2.81	9.64/3.34
MPN (log)	16.40/0.31	14.87/0.53	13.45/0.70	11.84/0.63
Sulphates (mg/l)	4.005/0.61	2.51/0.23	2.00/0.21	1.31/0.24
Sulphides (mg/l)	1.96/0.27	1.5/0.38	1.71/0.627	0.96/0.388

4.2.2 Performance of a UASB reactor

UASB reactor is supposed to work as a primary treatment unit and stabilize the sludge with typical COD removal efficiency of 70-75%. Removal of pathogens and nutrients is very small. The organic matter removed is mostly converted into biomass. Nutrient removal mostly occurs through assimilative use of anaerobic active biomass.

BOD and COD removal efficiency of UASB reactor can be calculated by using empirical equations.

$$E_{\text{COD } 1} = 100 \times (1 - 0.68 \times t^{-0.35})$$

$$E_{\text{COD } 2} = (1 - E_{\text{COD } 1}) (1 - 0.68 \times t^{-0.35})$$

Where

E_{COD} = Efficiency of UASB reactor in terms of COD removal (%)

t = Hydraulic retention time (hours)

0.68 = Empirical constant

0.35 = Empirical constant

$$E_{\text{BOD } 1} = 100 \times (1 - 0.70 \times t^{-0.50})$$

$$E_{\text{BOD } 2} = (1 - E_{\text{BOD } 1}) (1 - 0.70 \times t^{-0.50})$$

Where

E_{BOD} = Efficiency of the UASB reactor of BOD removal (%)

t = Hydraulic retention time (hours)

0.70 = Empirical constant

0.50 = Empirical constant

Table 4.7 Efficiencies calculation for the UASB reactor

	COD removal efficiency (%)	COD removal efficiency (%)	BOD removal efficiency (%)	BOD removal efficiency (%)
Sampling	Calculated	Observed	Calculated	Observed
1st	63.46	77.7	74.48	84.5
2nd	64	85.7	68.67	78.2
3rd	65.75	88.8	69.89	84.2
4th	63.35	84.2	71.88	84.7
5th	65.23	83.3	73.92	77
6th	65.46	81.9	74.6	77.9

Observed removal efficiencies are 77.7-88.8 % for COD and 77-84.7 % for BOD while expected efficiencies calculated according to equations described above are 63.23-65.75% for COD and 68.67-74.6% for BOD. This indicates that the equations were underestimating the efficiencies and this may be because of the differences in the characteristics of sewage being treated.

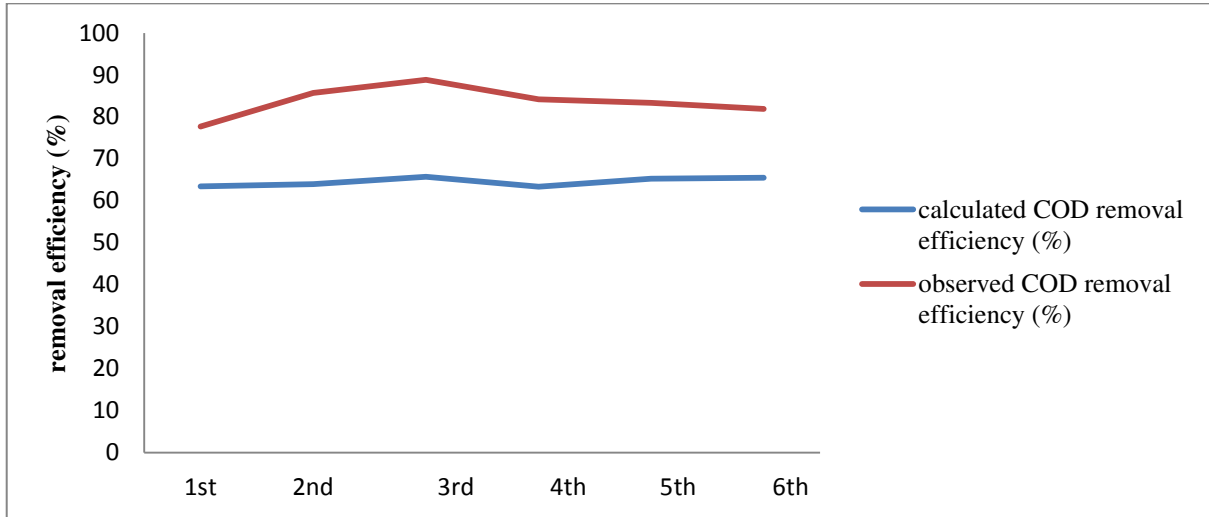


Fig 4.1 Calculated and observed COD removal efficiencies

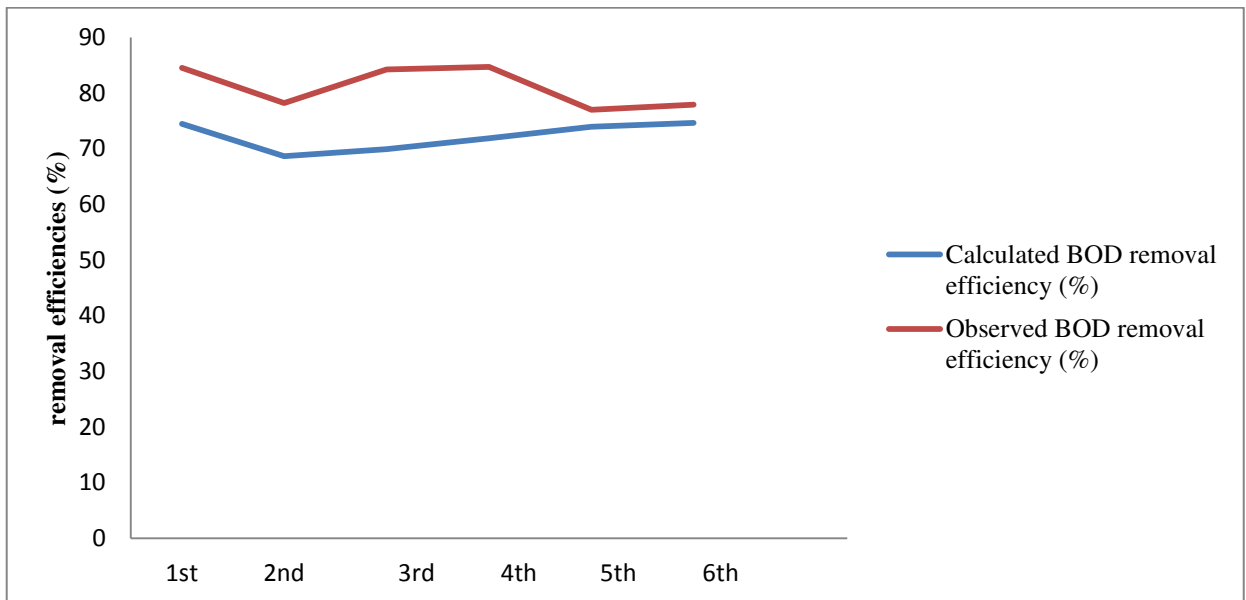


Fig 4.2 Calculated and observed BOD removal efficiencies

4.2.3 Performance of Facultative pond

Area of facultative pond is 1050 m² and its designed HRT is 1.5 days. Designed surface loading rate according to equation $\lambda_s = 350 \times (1.107 - 0.002 \times T)^{(T-25)}$ at 21°C is 290 kg/ha.d. Facultative ponds are supposed to reduce BOD by about 83.5% and do not change much with increasing temperature. The total nitrogen removal efficiency can be calculated by using equation:

$$C_e = C_o \exp [-\{0.0064 \times (1.039)^{T-20}\} \{\theta + 60.6 (\text{pH}-6.6)\}]$$

Where:

C_e = Ammonical nitrogen concentration in effluent pond (mg N/L)

C_o = Ammonical nitrogen concentration in influent pond (mg N/L)

T = temperature (°C)

pH = 7.3 exp (0.0005A_i)

A_i = influent alkalinity (mg CaCO₃/L)

Table 4.8: Nutrients removal efficiencies of Facultative pond

Sampling	Calculated nutrients removal efficiency (%)	Observed nutrient removal efficiency (%)
1 st	45.4	40.5
2 nd	47	41
3 rd	54.6	36.2
4 th	61.6	45.7
5 th	63	67.8
6 th	75.4	79

The calculated nutrient removal efficiencies are in range of 45.5% - 75.4% and observed efficiencies are in range of 36.2% - 79%.

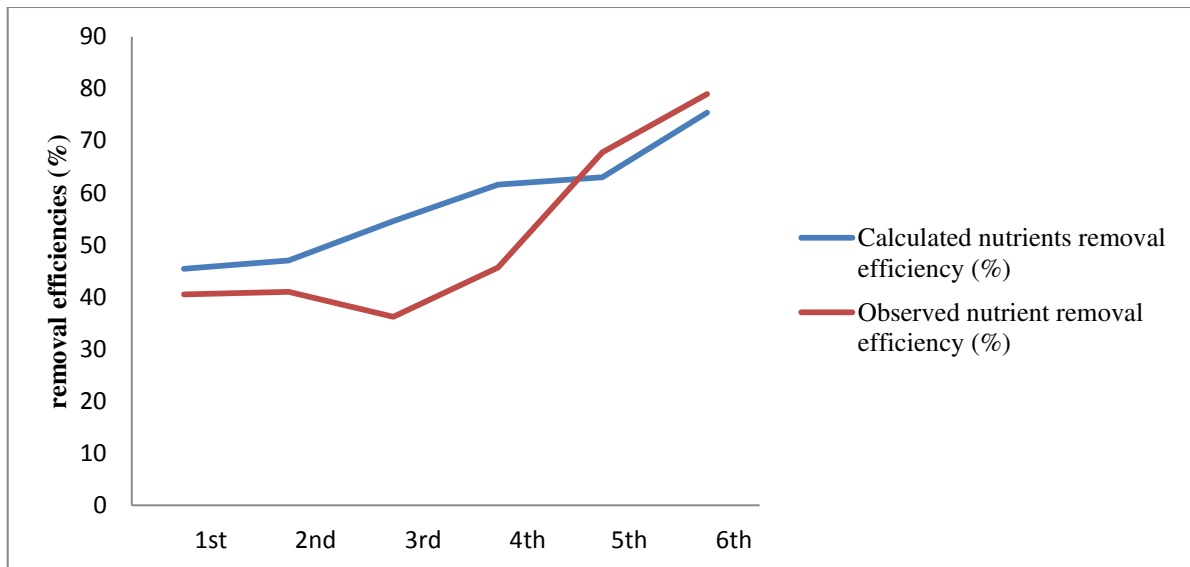


Fig 4.3: Calculated and observed nutrient removal efficiencies

Pathogen removal efficiency can be estimated by using following equation:

$$\frac{N_e}{N_o} = \frac{1}{(1 + k_{b(T)} \theta)}$$

Where:

N_o = pathogen concentration in influent (org/100ml)

N_e = pathogen concentration in effluent (org/100ml)

θ = Hydraulic retention time

$k_{b(T)}$ = pathogen coefficient

$$k_{b(T)} = k_{b20} \theta^{(T-20)}$$

Where:

k_{b20} = pathogen coefficient at 20°C, taken as 2.6.

θ = temperature coefficient, taken as 1.19.

Table 4.9: Pathogens removal efficiencies of Facultative pond

Sampling	Calculated pathogen removal efficiency (%)	Observed pathogen removal efficiency (%)
1 st	86.12	99
2 nd	88	99.2
3 rd	95.5	97.9
4 th	98	99.5
5 th	98.3	99.6
6 th	99	98

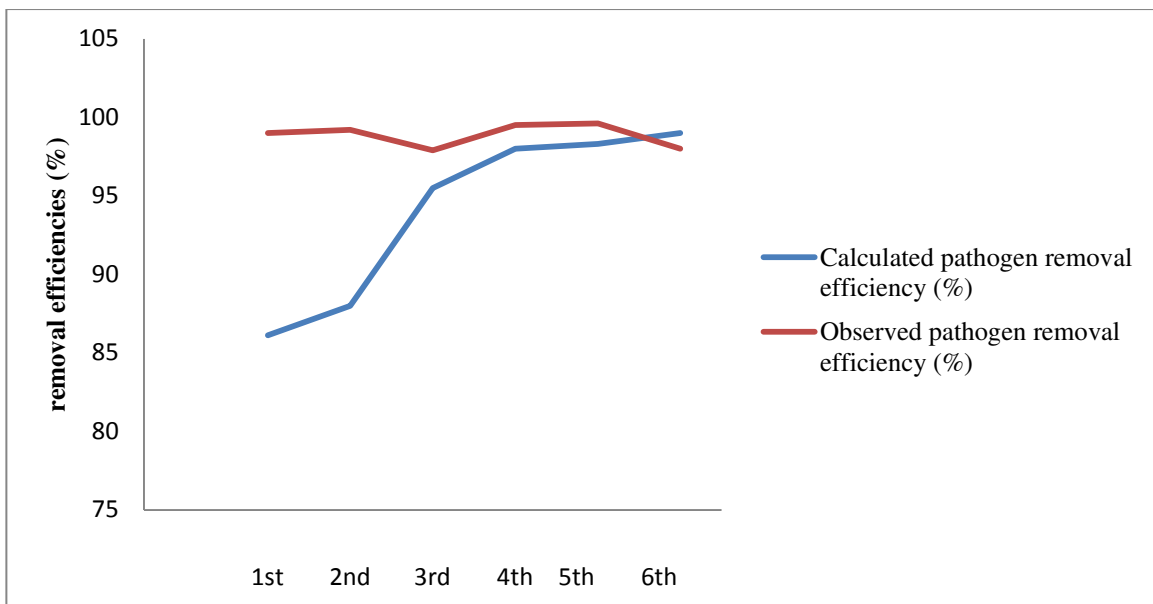


Fig4.4 Calculated and observed pathogen removal efficiencies

CHAPTER-5

CONCLUSION

Performance analysis of the sewage treatment plant was carried out in order to comment on the efficiency of the plant for treating the sewage water. The treated effluent was found almost in accordance with the standards prescribed by Punjab Pollution Control Board. BOD, COD, MPN, nutrients in the treated effluent were 21.51 mg/l, 42.33 mg/l, 11.84 log units, 9.64 mg/l respectively. BOD, COD, pathogen, nutrients removal efficiency of the STP is 81.08%, 83.6%, 98.86% and 51.73% respectively. Overall performance of the STP plant was satisfactory except for the removal of nitrogen. Low nitrogen removal efficiency may be due to high TSS contributed by algal cells resulting in the loss of greater amount of nitrogen in the effluent. Regular maintenance of sewage treatment plant is highly recommended. The treatment plant needs to be expanded to effectively treat sewage that it receives. Discharge of the final effluent for the irrigation may not cause health risks and other environmental problems.

CHAPTER-6

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