Performance assessment and design analysis of UASB based Sewage Treatment Plant

A Dissertation

submitted in partial fulfilment of the requirement

for the award of degree of

Masters of Technology

in

Environmental Science and Technology

Submitted

By

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July 2014

DECLARATION

I, the undersigned, hereby declare that the research work presented in the M.Tech project entitled **"Performance assessment and design analysis of UASB based Sewage Treatment Plant"** has been carried out by me under the supervision and guidance of **Dr. A.S. Reddy, Associate Professor, 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/elsewhere.

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CERTIFICATE

This is to certify that thesis entitled, **"Performance assessment and design analysis of UASB based Sewage Treatment Plant"** submitted by **Mr. Bikramjeet Singh Ghuman** in partial fulfilment of the requirements for the award of **Masters of Technology** degree in **Environmental Science & Technology** at **Thapar University, Patiala** is an authentic work carried out by him 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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ACKNOWLEDGEMENT

It is matter of immense pleasure to acknowledge my debt to my revered teachers and Supervisor **Dr. A.S. Reddy, Associate Professor and Head**, School of Energy and Environment, Thapar University, Patiala. It is because of his priceless intellectual guidance, innovative and constructive ideas for having given me complete independence, affectionate encouragement to put my desire and thought, which paved the way for the successful completion of this work. It is indeed my privilege to work under him.

I am also thankful to **Mr. Amarpreet Singh Arora** (Research Scholar) and non-teaching staff members of the department for their invaluable cooperation and help during the entire tenure of my studies in the department. I take this opportunity to thank my friends**Navroop Kaur, Priyanka Saini, Akshay Mahajan** for their help and moral support.

Deep heartedly, I thank my parents and my family members for their encouragement, blessings and motivation at each and every step.

Last, but not least, I thank **God** for giving me strength to overcome difficulty, which crossed my way to be a pole star.

Thank you for making this a reality.

Bikramjeet Singh Ghuman

Abstract

Biological treatment technologies of wastewater have undergone many developmentsover the years.With alarming growth rate of human population, high energy requirements all over the globe, scarcity of fresh water resources and inefficient water and wastewater managements; there arises the need for use of sophisticated and reliable wastewater treatment technologies. In relation to this; UASB based sewage treatment plants are of great significance with less input energy, high organic removal efficiency, biogas production etc. In this research work; studies were aimed at performance assessment and design analysis of UASB based Sewage Treatment Plant. Collecting representative samples for estimation of wastewater parameters, obtaining error free results and using these data values for validating design equations were the major objectives. At the end of project work, conclusions were drawn regarding various process efficiencies of this STP, non compliances and design equations.

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List of abbreviations

STP	Sewage Treatment Plant
P.P	Polishing Pond
UASB	Upflow anaerobic sludge blanket
(E)	Efficiency
T	Temperature
Ɵ, HRT	Hydraulic Retention Time
F.C	Faecal coliform

Chapter 1
Introduction

1.1 Background

Water scarcity and rapid depletion of water resources is a major problem in developing as well as developed countries. In the present scenario rivers are dying up and water levels are going down day by day making the discharge of treated wastewater an essential component for preserving the fresh water quality. There is a strong need for research and development in the area of wastewater treatment. Furthermore, existing process efficiencies must be improved and controlled effectively (**US geological survey, 2014**).

Sewage is one of the greatest sources of water pollution. Hence appropriate Sewage treatment technology is needed which is compatible with the atmospheric conditions as well as financial resources. Anaerobic treatment processes are widely accepted and useful for sewage treatment in areas with high temperature. Low initial and operational costs, need for less land, high organic removal efficiency, low sludge production, net energy benefit through the production of biogas makes it an obvious choice among other anaerobic processes. Various anaerobic treatment processes include anaerobic suspended growth, up flow and down flow anaerobic attached growth, fluidized-bed attached growth, anaerobic lagoons, membrane separation anaerobic processes and UASB (Up flow anaerobic sludge blanket). Among the various anaerobic reactors developed so far, the UASB reactor has been found to be relatively simple and economical because it requires neither added substratum as anaerobic filters nor effluent recirculation which is needed in fluidized bed reactors (**Metcalf & Eddy, 2004**). Figure 1.1 shows a typical UASB reactor.

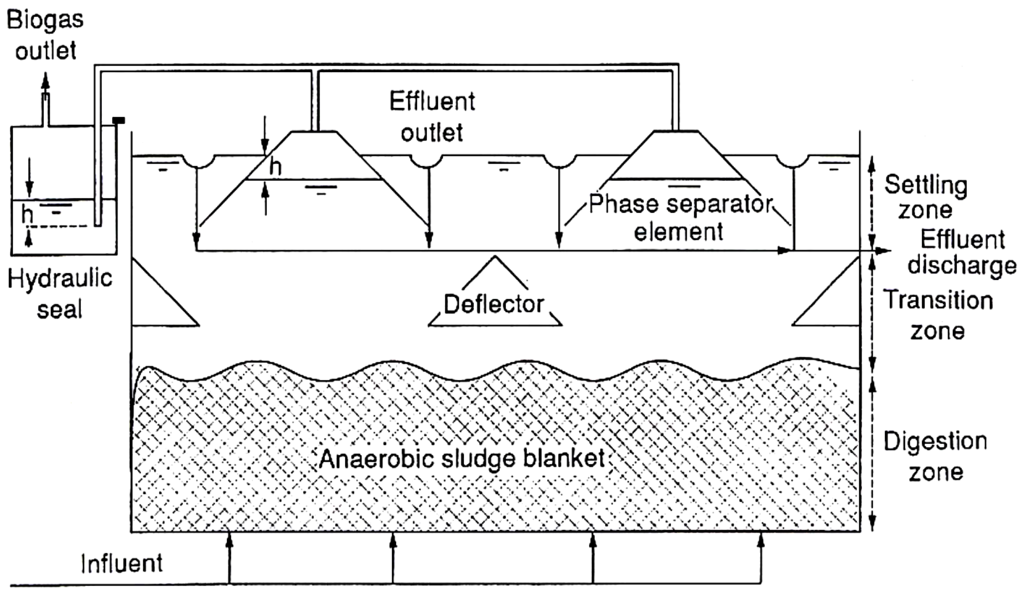

Figure 1.1: Structure of a UASB reactor

This research work was focused on UASB process which allows the use of high volumetric loadings compared to other anaerobic processes. In the current study work we have comprehensively reviewed the design considerations of UASB by analyzing various process parameters such as TSS, Turbidity, BOD, COD, Sulphates, Chlorides, Alkalinity, Acidity, TKN, Total phosphorous, Coliform count. For this purpose, Sewage Treatment Plant of Ludhiana with capacity of 111 MLD was selected. Monthly monitoring and sampling from selected units of the STP namely Inlet, UASB reactor outlet, Polishing unit outlet, and Final chlorination unit outlet was performed. Based on the results obtained during sample analysis the design considerations of the UASB reactor were reviewed along with the performance analysis of the reactor.

1.2 Objectives of the work

Following research objectives were framed for addressing the proposed research problem

1. Performance monitoring of Sewage treatment Plant

2. Design analysis of UASB

3. Design analysis of polishing ponds

1.3 Importance and usefulness of work

The findings of this work will be useful for improving the performance of STP Ludhiana. Based on the analysis certain finding and comments have been made on the current operations of STP and the treatment efficiency of the STP units. The equations developed could be used for efficient design of UASB and Polishing ponds in future.

1.4 Contents of the report

This thesis report comprises of six chapters along with references.

Chapter 1 (Introduction): It includes the background information about the work proposed. It states the objectives fulfilled during work and describes the usefulness of work along with the contents of the report.

Chapter 2 (Review of literature): It includes the literature survey about wastewater treatment technologies (UASB), design considerations for UASB reactor, post UASB treatment technologies such as use of polishing ponds for waste water treatment and design basis for polishing ponds.

Chapter 3 (Methodology): This chapter deals with the work elements formulated for fulfilling the proposed objectives. It describes the sampling procedures, methods for analyzing wastewater parameters for performance monitoring and design analysis of UASB reactor and polishing ponds.

Chapter 4 (Sewage Treatment Plant, Ludhiana): This chapter describes in detail; the various units of STP, their design criteria along with the dimensional details of the STP.

Chapter 5 (Results and discussion): This chapter includes the results obtained by the analysis, their utilization in design analysis along with the discussion.

Chapter 6 (Conclusion): This chapter provides the overall conclusions derived from this research work.

Chapter 2
Review of Literature

2.1 UASB reactor for waste water treatment

Upflow Anaerobic Sludge Blanket (UASB) reactor is a biological tank with upflow of wastewater and a settling tank. It was developed in The Netherlands **(Lettinga et al., 1980)**. The sludge bed, the sludge blanket, the gas-solids-liquid separator (i.e. 3-phase separator) and the secondary settling compartment above the separator are the four main components of UASB. Sludge bed has dense sludge with excellent settling profile. Sludge blanket is present at top of sludge bed with solids presenting lower concentrations and settling velocities. The sludge blanket consists of sludge particles in a mixture with the biogas formed, and is thus held in suspension. It is in these two compartments, the sludge bed and the sludge blanket, that the incoming wastewater is biologically degraded **(Chernicharo, 2007).**

The main prominent characteristic of UASB reactors is the phenomenon of granulation, i.e. formation of granules **(Chernicharo, 2007)** and establishment of a dense sludge bed in the bottom of the reactor, formed by accumulation of incoming suspended solids and bacteria. This process plays a major role in the successful operation and efficient performance of the plant **(Seghezzo et al., 1998)**. The granular sludge enables the retention of a very high number of microorganisms in the reactor, which leads to the decomposition of organic matter. It facilitates the treatment of a large scale treatment of waste with requirement of less space. The process of granulation is extremely complex **(Tiwari et al., 2006)**.

The anaerobic granular sludge consists of microbial communities, with millions of microorganisms per gram biomass **(Liu et al., 2002)**. The granules are grouped densely together and have excellent settle ability. Size of each granule is in the range of 0.1 mm to 5 mm. The microstructure of sludge granules depend upon substrate characteristic of the influent. For more complex substrates, generally the different bacterial populations will group together selectively in layers on top of each other **(Tiwari et al., 2006).**

Upflow velocity is the major parameter in the formation of sludge granules and their settling ability because of the pressure it exerts on the microbes adhering to each other **(Chernicharo, 2007**). Other parameters influencing the granulation were the temperature, pH, multivalent cations, exocellular polymers (ECP) and organic loading rate **(Tiwari et al., 2006)**.

The wastewater enters the bottom of the reactor and passes through the granules. The organic matter undergoes degradation and gets converted into methane and carbon dioxide. It further leads to the formation of gas bubbles which can provide adequate mixing and wastewater/ biomass contact. The rate of anaerobic digestion depends upon temperature. However, for sewage treatment only the mesophilic range is of relevant. At temperature below 30 °C, the digestion rate will decrease by about 11 % for each °C temperature decrease **(Van Haandel et al., 1994)**.

The flow pattern in the UASB reactor, especially in the sludge bed zone, is one of the most important factors to be considered for design to facilitate an efficient treatment. Factors such as hydraulic short-circuiting, bypass flow and mixing characteristics of flow pattern in the sludge-bed zone significantly affect the reactor performance by forming zones without wastewater known as dead zones **(Lema et al., 1991)**.

The granules rise in the reactor due to the bubbles, however they will settle in the tank since their settling velocities are greater than the upflow velocity (typically 1 m/h) **(Van Haandel and Lettinga., 1994)**.Anaerobic treatment processes were more attractive for countries with tropical climate, where the sewage temperature is generally above 20 °C **(Van Haandel et al., 1994).**The sludge loading rate and seed/biomass concentration were important variables which must be considered as systematic strategy for start- up of UASB reactors. Granulation time increased when the sludge loading rate value departed from an optimum value **(R P Singh et al., 1998)**.

(Lalit et al., 2005) carried out a study on 110 L UASB reactor which was operated at 25 degree centigrade. Wastewater with COD 308 mg/l was used as influent and study was carried out for 700 days. Granulation began after 9 months and with extensive studies the HRT was reduced to 9 months. Soluble and total COD removal was 81% and 75% respectively with methane production rate of 212 Nl/kg

COD removed and added 153 Nl/kg COD. Substrate conversion rate was 0.24 kg COD removed/kgVSS/day. Based on the COD mass balance, retained biomass, effluent VSS and neglecting biomass decay, an SRT of about 50 d was estimated to be critical for the accumulation of biomass in the reactor under the conditions used in our study. It was concluded that SRT must be higher than critical value so that the reactor may not lost the retained sludge.

Sludge blanket height plays an important role in the design and performance of UASB reactors **(Narnoli and Mehrotra, 1997)**. It prevents the sludge washout (critical operational problem) by regulating the solid concentration reaching the gas-liquid-solid (GLS) separation device. The biogas escaping from the bed lifts solids in the upward direction and forms the sludge blanket between the bed and the base of the GLS device. To minimize the sludge washout from the reactor a threshold concentration of the sludge (compatible with the design and performance of the GLS device) is maintained at the top of the blanket portion.

Many statistical models **(Bhunia and Ghangrekar, 2008)** have been developed to demonstrate that for getting higher percentage granulation and COD removal efficiency, influent COD and influent upflow velocity must have individual values in the range of 450-600 mg/l and 0.37-0.4m/h respectively. Formation of stable granules is beneficial for the successful operation of UASB reactors **(Show et al., 2004)**, as it increases the COD removal efficiency from 60–70% with flocculent sludge to more than 90% with granular sludge **(Jeong et al., 2005)**. Granulation in UASB reactors is favoured by a combination of high liquid upflow velocity and short hydraulic retention time.

In tropical countries the achieved COD removal efficiencies are in the range of 51–74% **(Sperling et al., 2005;Aiyuk et al., 2006)**.The pH, alkalinity and volatile acids are three environmental factors very important to the suitable operation of the anaerobic process and are closely related to each other. pH influences the growth rate of the microorganisms, the dissociation of compounds, for example ammonia, sulphide and organic acids and also affect many other factors. For example, an increased pH will lead to an increased fraction of free ammonia (NH_3), which is known to have an inhibitory effect on the anaerobic process **(Angelidaki et al., 2007)**.

System instability can easily be avoided by operating the reactor at convenient organic and hydraulic loading rates **(Foresti, 2001).**

(Mahmoud, 2008) investigated the treatment of high strength sewage in a one-stage upflow anaerobic sludge blanket (UASB) reactor and a UASB digester system. The one-stage UASB reactor was operated in Palestine at a hydraulic retention time (HRT) of 10 h and at ambient air temperature for a period of more than a year in order to assess the system response to the Mediterranean climatic seasonal temperature fluctuation. Afterwards, the one-stage UASB reactor was modified to a UASB-digester system by incorporating a digester operated at 35 degree centigrade. The achieved removal efficiencies in the one-stage UASB reactor for total, suspended, colloidal, dissolved solids and COD were 54, 71, 34, 23%, and 7%, respectively during the first warm six months of the year, and achieved only 32% removal efficiency for COD total over the following cold six months of the year. The UASB reactor performance was remarkably improved by the modification of the one-stage UASB reactor to a UASB-digester system as the UASB-digester achieved removal efficiencies for total, suspended, colloidal, dissolved solids and COD of 72, 74, 74, 62 and 70% respectively. Therefore, the anaerobic treatment of high strength sewage during the hot period in Palestine in a UASB-digester system was very promising **(Mahmoud, 2008)**.

Importance of UASB is due to generation of low strength waste waters and waste stabilization with release of energy as by- product. Evident reports can be seen on the successful operation of UASB in treating low-strength dairy industry wash waters [Chemical oxygen demand (COD 1200-2000 mg/L)]. The reactors achieved treatment efficiency of 75- 85% and were able to withstand shock-loads without adversely affecting the treatment efficiency. To assure appropriate performance of the system the presence of operational and monitoring personnel is a necessary condition and also operational control of the UASB is extremely important **(Chernicharo, 2007).** It was realised that regular evaluation of efficiency and operational stability must be critically carried out for efficient control **(Chernicharo, 2007)**.

The applicability of different kinetic models for the performance appraisal of upflow anaerobic sludge blanket (UASB) reactors treating wastewater in the range of 300–4000 mg COD/L have been explored. Three kinetic models namely Monod, Grau second-order and Haldane model are considered for the analysis. Both linear and nonlinear regressions have been performed to examine the best-fit among the kinetic models. In this process, five error analysis methods have been used to analyze the data. Apart from optimization of kinetic coefficients with minimization of associated errors, prediction of effluent COD has also been undertaken to verify the applicability of kinetic models. In both the cases, Grau second-order model is found to be the best class of fit for wide range of data sets in UASB reactor (**Bhunia and Ghangrekar, 2007**).

2.2 Challenges for the future

UASB performance must be studied and improved in winters. (**Tilche et al., 1991)** put forward one possible way to improve the performance of a UASB reactor at low temperatures. They suggested that surface area should be provided inside the reactor for biomass attachment and growth in the reactor volume above the sludge blanket. This could also be accomplished by replacing the typical gas/solids separator of the classical UASB reactor with filter media **(Lew et al., 2004)**. **(Van Haandel et al.,1994)** put forward the possibility to divide the process in two steps, where in the first step particulate organic matter is hydrolysed into soluble compounds, which are then digested in the second stage. At low temperatures, the excess sludge of the first reactor can be further hydrolyzed in a heated digester. After separation, the liquid phase is mixed with the effluent of the unheated hydrolytic reactor and submitted to the UASB reactor **(Van Haandel et al, 1994**).

A combination system was proposed by **(Aggrawal et al., 1997)** who evaluated the combination of a UASB together with a aerobic post-treatment system, for the treatment of domestic sewage at 7 to 30 °C. The system had a total COD removal of 70 % throughout the year, despite variations in outdoor temperature. Finally, another possibility, examined by **(Hellstrom et al., 2000)** was to separate the domestic wastewater from storm water and drainage, thereby creating a more concentrated wastewater, and treat it on-site to avoid it from getting cooled during the transport within the drainage system.

2.3 Design considerations for UASB reactors (Chernicharo, 2007)

2.3.1 Waste water characteristics

The fraction of particulate versus soluble COD is important in determining design loadings for UASB reactors as well as determining the applicability of the process. Fraction of solids increases the ability to form a dense granulated sludge.

2.3.2 Volumetric load

The amount of wastewater applied daily to the reactor, per unit of volume, is termed the volumetric hydraulic load.

$$VHL = (Q/V) \tag{2.1}$$

Where:

VHL = volumetric hydraulic load (m^3/ (m^3·d)

Q = flow rate (m^3/d)

V = total volume of the reactor (m^3)

Hydraulic retention time (HRT) is 1/VHL

Table 2.1: Applicable hydraulic detention times for raw domestic sewage in a 4m tall UASB reactor at various temperature ranges. (**Lettinga et al., 1991**)

Sewage treatment (^oC)	HRT (h)	
	Daily average	Minimum (during 4 to 6 h)
16 to 19	>10 to 14	>7 to 9
20 to 26	> 6 to 9	>4 to 6
> 26	>6	>4

2.3.3 Volumetric organic loadings

The volumetric organic load is the amount of organic matter applied daily to the reactor, per unit volume.

$$OLR = (Q.S_0)/V \tag{2.2}$$

Where:

OLR = organic loading rate (kg COD/m^3·d)

S_0 = influent substrate concentration (kg COD/m^3)

In the case of domestic wastewater, which contains low concentrations of organic matter, the OLR to be applied normally range from 2.5 to 3.5 kg COD/m^3d. Higher OLR is the potential for obtaining a more dense granulated sludge with consideration of economy and energy savings.

2.3.4 Upflow velocity

It is based upon the flow rate and reactor area; is a critical design parameter. Recommended Up flow velocity for domestic waste water is 0.8-1.0 m/hour. The upflow velocity v, is calculated from the relation between the influent flow rate and the cross section of the reactor as given below:

$$v = Q / A \qquad (2.3)$$

Where:

v = upflow velocity (m/h)

A = cross sectional area of the reactor (m^2)

Alternatively, the upflow velocity can also be calculated from the ratio between the height and the hydraulic retention time;

$$v = H / HRT \qquad (2.4)$$

Where:

v is the velocity

H is the height of the reactor.

The choice of appropriate height of the reactor depends on the required performance and economic considerations. Another important aspect is the position of the bottom of the reactor, relative to ground level. Construction costs can be reduced if the reactor bottom can be placed at such level that no pumping of influent is required. The reactor height also has importance for the efficiency of the organic matter removal, as the upflow velocity must not exceed the limit where sludge is washed out.

2.3.5 Reactor volume and dimensions:

The reactor volume based on acceptable organic loading rate (OLR) is given by:

$$V = \frac{Q \times C}{OLR} \tag{2.5}$$

Where:

V = volume of the reactor (m^3)

Q = influent flow rate (m^3/d)

C = influent COD (kg COD/m^3)

V = total liquid reactor volume

A = area of cross section

OLR = acceptable organic loading rate (kg COD/m^3.d)

Height of the reactor H = V/A

2.3.6 Influent distribution system:

There must be a close contact between substrate and biomass. Gas production contributes to mixing in the reactor. Poor mixing can lead to the creation of preferential pathways through the sludge bed, i.e. hydraulic short circuits, which in the long-term will give a shorter sludge bed height and the formation of dead zones in the sludge bed (**Lettinga et al., 1991**). To avoid these problems, the influent flow should be introduced at several points from the reactor bottom (**Chernicharo., 2007**). Appropriate and equal flow must be distributed to each inlet point and any fluctuations must be detected (**Van Haandel., 1994**).The number of distribution pipes needed depend on the area of the cross section of the reactor. (**Chernicharo., 2007**) suggests that the following equation can be used to determine the number of distribution pipes;

$$N_d = \frac{A}{A_d} \tag{2.6}$$

Where:

N_d= number of distribution tubes

A = area of cross section of the reactor (m^2)

A_d = influence area of each distributor (m^2)

2.3.7 Three-phase separator

The gas, liquid, solid separator is an essential device of the UASB reactor. It serves several important functions: it collects biogas escaping from the liquid phase, it allows settling of the suspended solids in the upper part of the reactor, above the separator, and it helps preventing sludge washout from the reactor, thus allowing the system to be operated at high solids retention times (with a high sludge age). Gas removal and optimal settling conditions are maintained with help of three phase separator (**Van Haandel., 1994**).

The design of the GLS device should be made based on the characteristics of wastewater, the expected biogas production, the organic load applied, the type of sludge present in the reactor and the dimensions of the reactor. The separator should be constructed in such way that gas entrapped in the sludge can be released easily. However, at the same time as the biogas release rate should be high enough to avoid the formation of scum layer, sludge should also not be allowed to be pulled upwards and clog the gas exit piping (**Chernicharo, 2007**).

2.4 Post treatment technology

Air-stripping may represent the first post-treatment step subsequent to the UASB reactor. This is not only to remove dissolved volatile malodorous compounds, but also, to recover the dissolved biogas in order to prevent problems with odour to the surrounding environment **(Lettinga et al., 1983)**.

The effluent from UASB reactors usually requires further treatment in order to remove remaining organic matter, pathogens and nutrients. This post-treatment can be accomplished in conventional aerobic systems **(Seghezzo et al., 1998)**, trickling filter systems or wetlands **(Foresti et al., 2006)**. Post-treatment step has to be simple, compact and inexpensive **(Aggrawal et al., 1997)**. Effluent quality and recovery of resources should be the aim of post treatment (**Foresti et al., 2006)**.

2.4.1 Waste Stabilization ponds for treatment of waste water coming out from UASB reactor

Combined UASB and Polishing Pond technology is the most suitable option for sewage treatment in developing country like India as it removes organic and solids load without any energy input **(Ahmad et al., 2013)**.The UASB effluent has good transparency, so photosynthesis in the ponds is intense and pH is increased due to biological carbon dioxide consumption, accelerating the death rate of pathogens and opening the possibility of reducing nutrients: Nitrogen by desorption of gaseous NH_3 and phosphorus by phosphate precipitation **(Frassinetti et al., 1996)**.

Waste stabilization ponds (WSP) were considered a good choice for wastewater treatment, mainly in developing and/or warm climate countries. Their many advantages include: simplicity, low cost, low maintenance, robustness, and sustainability **(Mara, 2004)**. It removes BOD but does not remove suspended solids due to presence of algal cells. It is widely used in areas where the effluent is to be used for irrigation purposes without any requirement for disinfection **(Shilton, 2005)**.

Polishing/maturation ponds can provide further removal of organic matter (BOD), achieve high ammonia removal and produce effluents of excellent bacterial quality, as long as they are properly designed **(Sperling., 2005)**. Their results confirm a well established understanding that shallow polishing ponds designed for the removal of ammonia and coliform provide additional BOD removal and face no problems of organic overloading. The major operational problem encountered in WSPs is the excessive discharge of particles in the effluent caused by algal activity especially during the summer season. Therefore, it is essential to polish the effluent from the WSPs by removing over-discharged suspended solids (SS), biochemical oxygen demand (BOD), and nutrients**.**

2.5 Design considerations for polishing ponds (Mara, 1997)

The four most important parameters for WSP design are temperature, net evaporation, flow and BOD. Fecal coliform and helminths egg numbers. The usual design temperature is the mean air temperature in the coolest month (or quarter). This provides a small margin of safety as pond temperatures are 2-3 degree centigrade warmer than air temperatures in the cool season (the reverse is true in the hot season).The main design considerations are to find number of ponds in series and HRT per pond to give smallest total pond surface area. Some important points regarding design are:

- Depth and length to width ratios are taken as 1.0-1.5 m and 3-10 m respectively.
- Equal HRT for all the ponds.
- Minimum HRT of 3 days per pond.
- HRT of the first pond less than that of the preceding pond. These ponds are usually designed for a total HRT of 10-20 days.

2.5.1 The design equations used for fecal coliform removal in WSP

The first-order equation for fecal coliform (FC) removal in a completely mixed reactor;

$$N_e = N_i/(1 + k_{B(T)}\theta) \qquad (2.7)$$

N_e and N_i are the FC numbers per 100 ml of the anaerobic pond effluent and the raw wastewater, respectively; $k_{B(T)}$ is the first-order rate constant for FC removal in anaerobic ponds at T ℃, day^{-1}; and θ is the mean hydraulic retention time in the anaerobic pond (days) and is defined as the pond volume V in m^3 divided by the raw wastewater flow Q into the pond in m^3/day.

FC removal in dispersed flow reactors:

$$N_e = N_i[4a/(1 + a)^2]\exp[(1 - a)/2d] \qquad (2.8)$$

Where:

$$a = \sqrt{(1 + 4k_{B(T)}\theta\delta)}$$

$$k_{B(20)} = 0.92D^{-0.88}q^{-0.33}$$

$$k_{B(T)} = k_{B(20)}(1.07)^{T-20}$$

where q is the mean hydraulic retention time in days and D is the pond depth. $k_{B(T)}$is now the first-order rate constant for FC removal in a dispersed flow reactor at design temperature of T ℃, day^{-1}.

The retention time in the facultative pond depends on the permissible surface BOD loading at the design temperature T (^oC) and on the rate of net evaporation, but it should never be lower than a minimum of 4 days. The retention times in the maturation ponds must be less than that in the facultative pond, but never lower than a minimum of 3 days; additionally the surface BOD loading on the first maturation pond must not be greater than 75% of that on the facultative pond.

2.5.2 Design equation for helminths egg removal

Helminth eggs are normally removed by sedimentation, with the process occurring in the anaerobic or primary facultative ponds. If the final effluent is to be used for restricted irrigation, it is necessary to ensure that it contains no more than one egg per liter. Analysis of egg removal in the pond has yielded the following relation reported by (**Ayres et al., 1992**).

$$R = 100[1 - 0.14\exp(-0.38\theta)] \qquad (2.9)$$

Where R is percent egg removal and θ is retention time (day). The equation corresponding to the lower 95% confidence limit is: $R = 100[1 - 0.14\exp(-0.49\theta + 0.0085\,\theta^2)]$

2.5.3 The design equation for nutrient removal in polishing ponds

The equation for ammonia-nitrogen (NH_3 + NH^+_4) removal in individual facultative ponds was presented by **(Pano and Middlebrooks., 1982).** The equation for temperatures below 20^o C is as follows:

$$C_e = C_i / \{1 + [(A/Q)(0.0038 + 0.000134T)\exp((1.041 + 0.044T)(pH - 6.6))]\} \qquad (2.10)$$

And for temperatures above 20^o C:

$$C_e = C_i / \{1 + [5.035x10^{-3}(A/Q)][\exp(1.540x(pH - 6.6))]\} \qquad (2.11)$$

Where:

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

Ci = ammonia-nitrogen concentration in pond influent (mg N/L)

A = pond area (m^2), and Q is influent flow rate (m^3/day)

Total nitrogen removal in the individual facultative and maturation ponds was presented by Reed (1995), as follows:

$$C_e = C_i \exp\{-[0.0064(1.039)^{T-20}][\theta + 60.6(pH - 6.6)]\} \qquad (2.12)$$

Where:

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

C_i = total nitrogen concentration in the pond influent (mg N/L)

T = temperature (^{o} C; range: 1-28^o C)

θ = retention time (days; range: 5-231 days)

The pH values used in the above equations may be estimated as follows:

$$pH = 7.3 \exp(0.0005 A)$$

Where:

A = influent alkalinity (mg $CaCO_3$/L)

2.5.4 Design on the basis of BOD surface loading rate:

It is recommended that design of polishing ponds must be on the basis of surface BOD loading (λ_s, kg/ha d), which is given by:

$$\lambda_S = 10 L_i Q / A_f \tag{2.13}$$

Where:

A_f = facultative pond area (m^2)

Q = flow rate (m^3/day)

L_i= influent BOD (Kg BOD/day)

λ_S = surface BOD loading (Kg/BOD/hectare/day)

2.6 Design of chlorination unit (Ahmed Sharaf, 2008)

Design of chlorination unit depends on dose needed, characteristics of water, design of mixers which is depending upon type of mixing needed. Chlorine contact basin have configuration of long plug flow reactors to eliminate formation of hydraulic dead zones. Length to width ratio is 20:1 to 40:1.Submerged baffles were used for better hydraulic performance. Long travel time in pipeline eliminates requirement of chlorine contact basin. A contact time of 30 minutes at design average daily flow is required after thorough mixing. Higher chlorine dose/ contact time is required for effluent containing higher microbial counts. Plug flow conditions are to be achieved in the contact basin. Length-to-width (L/W) ratios of greater than 40:1 is required for plug flow regime. The height-to-width ratio of the wetted cross section of the channel should not exceed 2:1. In rectangular tanks, longitudinal baffling to produce long, narrow flow channels with a serpentine flow pattern and with guide vanes at changes in direction should be used to produce an efficient contact basin. Cleaning and maintenance should be easy and skimming devices have to be provided.

Chapter 3
Methodology

Research objectives were achieved by working on the following work elements:

- Sample collection and analysis for performance monitoring of sewage treatment plant
- Design analysis of sewage treatment plant

3.1 Sample collection and analysis for performance monitoring of sewage treatment plant

3.1.1 Sample collection

Wastewater samples from various locations of STP were taken on monthly basis with established sampling techniques. Sampling techniques were aimed to collect the representative sample; and standard procedures were adopted during transportation, preservation and testing of water samples so as to obtain consistent results. Wastewater samples were collected in properly cleaned and autoclaved containers. Samples were brought and tested in environmental laboratories of the department so as to estimate various wastewater quality parameters, based on which design analysis of STP was done. Till the completion of analysis samples were kept in the cold room (2-8°C).

Various equipments such as BOD incubator, COD digester, spectrophotometer, laminar air flow cabinet, pH meter, turbidity meter, hot air oven were cleaned and calibrated at regular intervals. These were used for the estimation of various wastewater parameters. All the sampling procedures, storage procedures, testing procedures were followed as per APHA manual, 22nd edition.

In monthly sampling plan, four sampling points were identified namely; inlet of UASB reactors, outlet of UASB reactors (inlet of polishing pond), outlet of polishing pond (inlet of chlorination unit), and outlet of chlorination unit (final outlet). Table 3.1 enlists the estimated parameters at each of the selected sampling points.

Table 3.1: Sampling points and estimated parameters

Parameters	Inlet	UASB outlet	Polishing pond outlet	Final outlet
Acidity (mg/l as CaCo3)	✓	×	×	✓
Alkalinity (mg/l as CaCo3)	✓	×	×	✓
Ammonical nitrogen (mg/l)	✓	✓	✓	✓
BOD (mg/l)	✓	✓	✓	✓
Chlorides (mg/l)	✓	×	×	✓
COD (mg/l)	✓	✓	✓	✓
Faecal coliform/100ml	✓	✓	✓	✓
MPN(Total COLIFORM)/100ml	✓	✓	✓	✓
Organic Nitrogen (mg/l)	✓	✓	✓	✓
pH	✓	✓	✓	✓
Sulphates (mg/l)	✓	×	×	✓
Sulphide (mg/l)	✓	✓	✓	✓
Temp (degrees)	✓	✓	✓	✓
Total phosphorous (mg/l)	✓	✓	✓	✓
TSS (mg/l)	✓	✓	✓	✓
Turbidity (NTU)	✓	✓	✓	✓
Residual Chlorine	×	×	×	✓

The details of analytical techniques adopted for testing the samples is given in Table 3.2 below.

Table 3.2: Methodology for sample testing

S. No.	Parameters	Method (with reference from APHA manual, 22nd edition)	Part No.
1.	BOD	5- day test	5210 B
2.	COD	Open reflux method	5220 B
3.	MPN (Total coliform)	Total coliform fermentation test	9221 B
4.	Chlorides	Argentometric	4500-Cl^- B
5.	Acidity	Titration	2310 B
6.	Alkalinity	Titration	2320 B
7.	Temperature	Digital thermometer	2550 B
8.	pH	Electrometric	4500-H^+
9.	Sulphates	Turbidometric	4500-SO_4^{2-}
10.	Residual chlorine	Iodometric	4500- Cl B
11.	TSS	Dried at 103-105^{0}C	2540 D
12.	Turbidity	Nephlometric	2130 B
13.	MPN (Faecal coliform)	Serial dilution method	9221 C
14.	Total Phosphorous	Stannous chloride	4500- PD
15.	Organic nitrogen	Macro kjeldahl method	4500-Org B
16.	Ammonical nitrogen	Titrimetric	4500-NH_3 C
17.	Sulphide	Iodometric	4500-S^{2-}

3.2 Design analysis of Sewage treatment plant

Various empirical relations were used to design UASB based STPs; the important design considerations were waste-water characteristics in terms of composition and solids content, volumetric organic load, up-flow velocity, reactor volume, physical features including the influent distribution system, gas collection system etc.

An understanding of the process kinetics was vital in the design, development and operation of UASB reactors. Based on the biochemistry and microbiology of anaerobic process, kinetics provides a judicious basis for process analysis, control, and design. In addition to quantitative description of the substrate utilization rates, process kinetics was also influenced by operational and environmental factors affecting these rates. BOD, COD, TSS and total nitrogen of the treated effluent of the polishing pond were estimated. Performance of the polishing pond was studied in detail based on the above parameters.

3.2.1 Design analysis of UASB reactors

Design analysis of UASB reactors was carried out on the basis of COD removal efficiency, TSS removal efficiency, MPN removal efficiency of the reactors.

Respective equations for above parameters can be listed as:

- COD removal efficiency = $[(COD_{in} - COD_{out})/COD_{in}] * 100$ (3.1)
- COD (E) = $100\ (10.68*HRT^{(0.35)})$ (3.2)

Regression Analysis was also undertaken for COD (E) versus Temp., HRT, to validate the equation (3.1) and lastly to find new validated equation for COD (E).

Similarly, TSS removal efficiency can also be used for design analysis. Equations can be listed as:

- TSS removal efficiency = $[(TSS_{in} - TSS_{out})/TSS_{in}]*100$ (3.3)
- TSS (E)= $102*HRT^{(-0.24)}$ (3.4)

Regression Analysis of TSS (E) versus Temp, HRT, and chlorides concentration. Equation for TSS (E) was also validated, TSS and HRT correlation was found out.

Design analysis based upon MPN removal efficiency.

In this step, MPN reduction/100 ml was observed and $N_{anaerobic}$ (per 100 ml) and $K_{B(T)}$ were calculated from the following empirical relations.

- $N_{anaerobic}$(per 100 ml) = $N_{raw}/(1+K_{B(T)}.\Theta_{UASB})$ (3.5)
  Where:
  $K_{B(T)} = 2.6(1.19)^{T-20}$, Θ_{UASB} = HRT(days).
- Equation (3.3) was then validated and regression equation was found for M (N_{UASB}/N_{raw}) versus Θ (days), Temp. (^{0}C)

3.2.2 Design analysis of Polishing Unit

Polishing unit was designed for BOD removal efficiency of 40% and TSS removal efficiency of 50%.Here, we calculated removal rate of BOD (kg/hec. day) by using the relation;

$$\lambda_s = 350(1.107 - 0.002T) \quad \text{and} \quad \lambda_r = (0.79 * \lambda_s) + 2 \qquad (3.6)$$

and after that removal rate was calculated from the observed values of BOD.

Ammonical nitrogen in the effluent was given by;

$$C_e = C_i / \{1 + [5.035x10^{-3}(A/Q)][\exp(1.540x(pH - 6.6))]\} (3.7)$$

Where:

C_e = ammonia-nitrogen concentration in pond effluent (mg N/L)
Ci = ammonia-nitrogen concentration in pond influent (mg N/L)
A = pond area (m^2), and Q is influent flow rate (m^3/day)

We calculated the concentration of ammonical nitrogen in the effluent and then it was compared with the results obtained from the sample analysis in lab.

Analysis of polishing unit was also done on the basis of Fecal Coliform count (mean values obtained over six months sampling period) in the effluent which was given by the relation:

$N_e = N_i/(1 + k_{B(T)}\theta$

where, N_e and N_i are the FC numbers per 100 ml of the anaerobic pond effluent and the raw wastewater, respectively; $k_{B(T)}$ is the first-order rate constant for FC removal in anaerobic ponds at T °C, day^{-1}; and θ is the mean hydraulic retention time in the anaerobic pond (days). The results obtained from this was compared with the results obtained from actual analysis.

Chapter 4
Sewage Treatment Plant, Ludhiana

4.1 Detailed Description of Sewage Treatment Plant, its units and design considerations

The STP in question is located in Ludhiana at village Bhattiyan. It has been designed for a flow of 111 MLD. Wastewater from Ludhiana city undergoes treatment at this STP after which it is ultimately discharged into the Sutlej River. The STP was made operational in 2007 based on UASB (Upflow Anaerobic Sludge Blanket) Technology under Sutlej Action Plan (SAP). Punjab Water Supply &Sewerage Board manages this STP. Main units of the STP are:

- Bar screen
- Main pumping station (MPS)
- Automated Bar Screen Chamber
- Grit chamber and grit channels
- UASB reactors
- Pre aeration tank
- Polishing Pond
- Chlorination unit
- Biogas handling system (biogas holder, biogas scrubber, biogas flare)
- Sludge handling system (sludge sump and pump, sludge drying beds)

Working of the STP: The 111 MLD UASB sewage treatment plant receives sewage from the main pumping station (MPS). The MPS is located within the STP site. For better operation and maintenance of the STP, the MPS sump is divided into two equal parts and the pumping systems are provided to cater both the sections. The sewage from the inlet chambers flows through screens. Screening is done prior to pumping and after pumping. Two types of screens; mechanical and manual screens are used. When the mechanical screens are under repair and maintenance; the manual-screens are used. After screening, the sewage is treated for grit removal in the mechanical degritter.

After degritting, the sewage enters a collection chamber from where it is conveyed into three division boxes. The central division box is catering to all the “nine” reactors whereas the side divisional boxes are catering to four and five reactors respectively. The flow from division box goes into the distribution boxes placed over the UASB reactor. There are “nine” reactors.

The process flow diagram of the STP is shown in Figure 4.1:

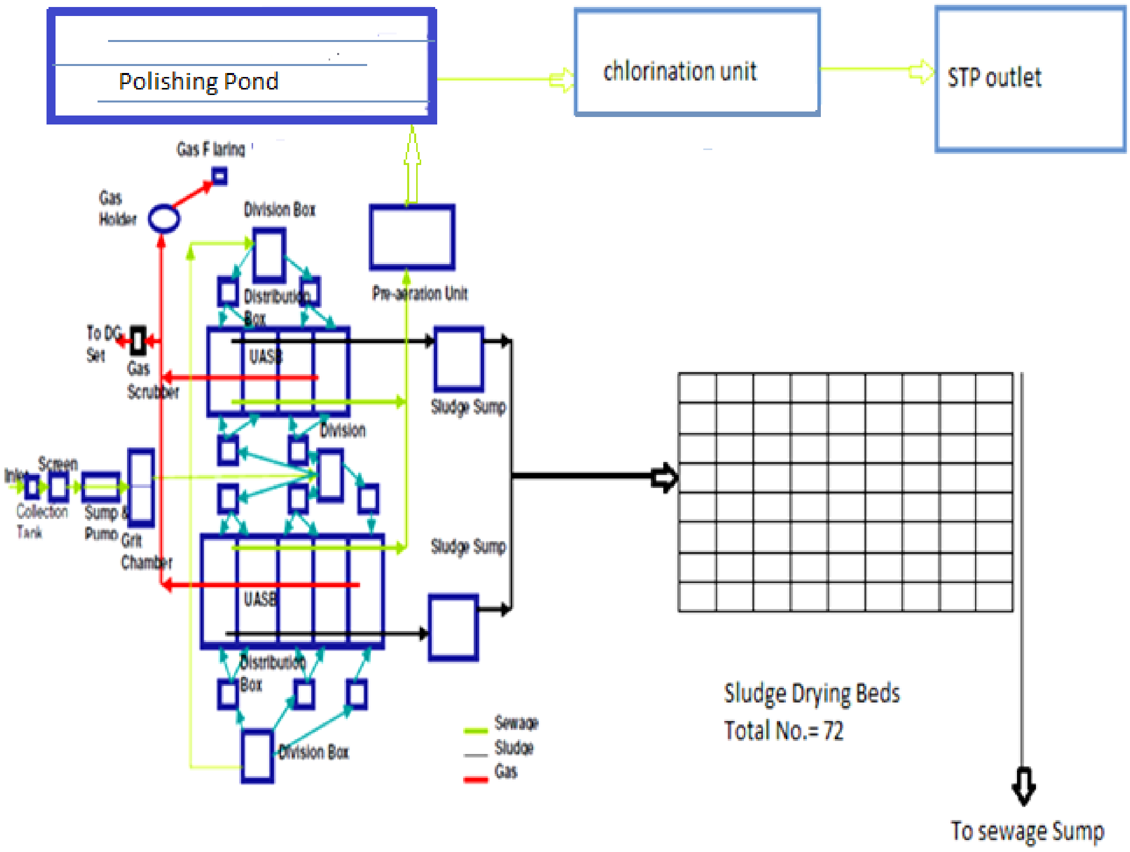

Figure 4.1: Process Flow Diagram of Sewage Treatment Plant

From the two distribution boxes, the sewage is distributed further catering to 20 feed boxes placed on the top of the reactor. From each feeding box, there are 12 pipes of 65 mm distributing the sewage uniformly over the bed of the reactor. There are a total of 240 down take pipes in one reactor. In the UASB reactor, the bio-degradation of sewage and settling of solids takes place. The UASB reactor is 32mm wide, 30m long and 4.7m high upto the top of Gas-liquid-solid separator. Each reactor is designed to handle an average flow of 12.5 MLD. The treated effluent flows upward through the GLSS to the effluent gutters placed over the top of the reactor on either side of the gas domes. In one reactor, there are 8 bays of gas domes each of 4m used and 16 effluent gutters, one on either side of each gas dome. The treated effluent from UASB reactors is conveyed through a Common Effluent Channel (CEC). The common effluent channels are further connected to a pipe, which carries the treated effluent to the pre-aeration unit meant to remove the dissolved gases of the effluent.

The final polishing unit (FPU) has been designed for 44 hours retention time to meet the desired effluent standards for river discharge as per regulatory guidelines. In the FPUsettling of suspended solids, removal of BOD and COD, coincidental removal of pathogens and nutrients take place. The treated effluent after FPU is discharged to River Satluj by gravity through a Final Effluent Channel of Trapezoidal section. Chlorination unit has been provided to reduce Coliform count. Chlorine applied is 8 ppm.

The excess sludge produced in the reactor is removed on a regular basis. The sludge to be removed is withdrawn with the help of the four sludge withdrawal pits, two pits are provided on longer side of the reactors. Each sludge pit has two tapping points for sludge withdrawal and one tapping point for water to flush the sludge pipelines. The specified quantity of sludge is withdrawn equally from all four-sludge pits. There are two sludge sumps one for each of the bay of reactors. From the sump the sludge is pumped to the sludge drying beds. The sludge on the sludge drying beds undergoes dewatering and gets dried depending upon local weather conditions. The dried sludge cakes are removed from the beds and have the potential to be used as a soil conditioner. The beds can be subsequently used for drying of sludge again in another cycle. The filtrate from the sludge drying beds flows by gravity to the inlet sump of MPS.

The biogas produced in the reactors is separated with the help of the Gas Liquid Solids Separators (GLSS). The biogas collected in the gas domes is taken through gas pipes placed along the longer side of the reactor. The gas hoods are connected with the gas pipes through flexible reinforced PVC pipe. The gas pipes are connected to common headers that finally lead through moisture traps to the biogas holder. There is one bio-gas holder. Dual fuel engine generators are in operation to generate electricity using the biogas and diesel. The power generated is consumed at the STP, office building, laboratory and MPS.

Design Details of the Units:

4.1.1 Main Pumping Station

Figure 4.2: Main pumping station

- 10 pumps of 36 MLD capacity.

4.1.2 Bar screen

Figure 4.3: Bar screen before pumping

Table 4.1: Bar screen characteristics

Parameter	Value
No. of channels	2 (one mechanical + one manual)
Max. Velocity through bars	1.2 m/s
Min. channel velocity	0.3 m/s
Bar spacing (fine mechanical screens)	6mm
Bar spacing (manually operated racks)	20 mm
Clear section x-section area	2.138 m^2
Clear width of waterway	2.25 m
No. of bars	375
Width	4.5 m
Water depth	0.95 m
Length of channels	8.00 m
Velocity in channel at peak flow	0.6 m/s
Velocity through screens at peak flow	1.2 m/s
Angle of inclination of bar screen	60 degrees

Figure 4.4: Manual screen after pumping

Figure 4.5: Mechanical screen after pumping

4.1.3 Grit chamber and grit channels

Figure 4.6: Grit channels

Table 4.2: Characteristics of Grit channel

Parameter	Value
Max. channel velocity	0.2 m/s
Grit settling velocity	0.0195 m/s
Grit removal interval	alternate day
Minimum Detention time	60 seconds
Surface Overflow Rate (SOR)	1123 $m^3/m^2/d$
No. of channels	3 (2 working, 1 standby)
Water depth	0.95 m
Width of channel	3.5 m
Length of channel	14 m
Retention time	73 seconds
Horizontal Velocity	0.193 m/s

4.1.4 Mechanical Degritting Unit:

No. of units	2
Area of each unit	84 m^2
Diameter	10.3 m

4.1.5 Upflow Anaerobic Sludge Blanket Reactor

Division Box and Distribution Box

The degritted sewage from mechanical degritter or grit channels is collected in the outlet box attached with the grit channels. Here sewage is divided into three streams discharging the sewage to the three division boxes. One division box is located in the centre of two bays of reactors, feeding to 9 distribution boxes whereas the other two division boxes are kept on each side of reactors to feed 9 distribution boxes in all for both the bays of reactors. One distribution box is located on each long side of UASB reactor. The flow from the division box is received in the central compartment of the distribution box. The flow is distributed over 4 compartments through overflow weirs. The flow from distribution boxes is fed to the 20 feeding boxes placed on top of each UASB reactors.

The UASB reactors were designed to take peak flow rates of 2.0 times of the average flow. For short periods even higher flow rates can be allowed. The UASB reactor consists of two parts. The lower part comprising of the reaction compartment where the biological breakdown process is achieved and the top part consisting of three phase separator (GLSS) where separation of gas, solids and liquids takes place.

Figure 4.7: UASB reactors

Table 4.3: UASB design characteristics

Parameter	Value
Minimum upflow velocity	0.55 m/ h
Maximum upflow velocity	1.1 m/h
Sludge Bed Concentration	65 kg TSS / m3
SRT	38 days
Angle of gas collector	50 degree
Angle of deflector beam	45 degrees
Number of reactors	9
Average flow to each reactor	12333.34 m^3/ d or 513.89 m^3/hr
Surface area of each reactor	513.89 / 0.55 = 935 m^2
Length of reactor	32 m
Width of reactor	30 m
Effective water height in reactor	4.70 m
HRT at avg. flow	8.49 hrs
No. of gas collectors	8
Width of gas collectors	3.0 m
Height of gas collectors	1.49 m
Gas hood width	0.50 m
Gas liquid surface	12.5%
The reactor height	5.20 m
Number of feeding points	960/4=240
No. of feed inlet boxes	20
No. of feed pipes per box	12
Sludge layer height	0.7 m
Settling zone height	1.5 m
No. of sludge sampling point in a reactor	2
Sludge drain height	0.7 m to 1m
Diameter of sampling pipe	2 inch
Sludge pits for one reactor	4
Space between sludge bottom and sampling points	10 cm
No. of distribution boxes for a reactor	2

4.1.6 Pre-Aeration Tank

Figure 4.8: Aeration unit

Table 4.4: Aeration unit details

1	Average flow	111000 (m^3/day)/ (4625 m^3/hr)
2	Retention time	30 minutes
3	Depth	2 m
4	Tank Area	1156 m^2(Square tank of 34 m* 34 m)

4.1.7 Polishing Unit

These are designed for the removal of BOD, nutrients and most importantly for removal of pathogens (coliforms and helminths eggs). Polishing ponds are used to improve the quality of effluents from efficient anaerobic sewage treatment plants like UASB reactors, so that the final effluent quality becomes compatible with legal or desired standards. Removal is dependent upon time, temperature, pH, light intensity and Dissolved oxygen. Sedimentation and photosynthesis plays an important role for the removal of viruses and helminths eggs respectively.

Figure 4.9: Polishing Unit

Table 4.5: Polishing unit details

1	HRT	1.83 days (44 hours)
2	Depth	1.25 m
3	Free board	0.25 m
4	Length	630 m
5	Width	270 m

4.1.8 Chlorination unit

Chlorination is the final step in the treatment process. The main objective of this chlorine addition is to disinfect the water and maintain chlorine residuals that will remain in the water as it travels through the distribution system. Depending on the pH conditions required and the available storage options, different chlorine-containing substances can be used. The three most common types of chlorine used in water treatment are: chlorine gas, sodium hypochlorite, and calcium hypochlorite. At this STP, chlorine dose of 5 ppm is added to polished effluent effluent by using chlorine gas.

4.1.9 Sludge handling system

Proper functioning of the plant the excess sludge accumulation in the UASB reactors has to be removed and an appropriate amount is maintained. The excess amount of sludge has to be discharged regularly and uniformly to avoid the occurrence of channeling in the sludge bed. Therefore, discharge points have to be distributed evenly along the perimeters of the UASB reactor units. The withdrawal will be in sequence and will be gradual. The excess sludge will be withdrawn from the UASB reactors from the bottom or middle valve into the sludge sump. The valve provided at top will be used for flushing the sludge line. The excess sludge should be removed on regular basis.

Table 4.6: Sludge handling system details

Parameter	Value
No. of sludge pits in one reactor	4
No. of tapping points	2/pit(One at bottom & other at 1.5 m from the bottom)
Total no. of tapping points per reactor	8
Frequency of sludge discharge	every day from each reactor
Volume of sludge to be removed from one reactor	46 m^3 /d
Capacity of the sump = sludge from two reactors or sludge from one reactor on alternate day	92m^3
Diameter of sump	10 m,
Assumed pumping time	45min
Pump discharge rate	121 m^3/hr
Head of pumping	25 m
Pump efficiency	70 %, power = 20 HP(1 working + 1 standby)

4.1.10 Sludge drying beds

Table 4.7: Sludge drying beds details

Parameter	Value
Drying cycle	7 days (incl. loading & unloading) from two reactors and two SDB's will be fed simultaneously.
Sludge discharge conc.	70 kg TSS/m^3
Sludge height on SDB	40 cm
Volume of sludge to be removed from two reactor	92 m^3/d
Size of each SDB	256 m^2
No. of drying beds to be filled per day	9 (one from each reactor)
No. of drying beds	72
Sludge height after drying	10 cm
Diameter of sludge sump	10 m

4.1.11 Bio-gas holder

Biogas holder is provided to store the bio-gas for generation of electricity. Dual fuel engines are installed. The holder capacity is of 6 hour storage. In the running of the engines only 30% of the fuel is the biogas whereas 70% is diesel. Biogas holder is shown in Figure 4.10.

Figure 4.10: Biogas holder

Table 4.8: Biogas holder details

Parameter	Value
Storage Time	6 hrs.
Type	MS Floating dome water sealed in an RCC tank
Biogas production	4274 m^3/d
Holder capacity	(4274/24)*6= 1069 m^3
No. of units	1
Diameter	16 m
Biogas Holder height	5.32 m

Chapter 5
Results and Discussions

5.1 Results of the Sample Analysis

The sampling was done in the middle days of every month starting from November 2013 to May 2014. By following a scheduled sampling plan we identified four locations for sampling. These locations were:

- Inlet of STP (Inlet of UASB)
- UASB outlet (Inlet of polishing unit)
- Polishing unit outlet (Inlet of chlorination unit)
- Chlorination unit outlet (STP outlet)

Multiple samples were obtained from each location in four litre capacity containers. Parameters analyzed for STP inlet have been listed in table 5.1:

Table 5.1: Parameters analysed and the results obtained at Inlet of STP

Parameters	November	January	February	March	April	May	Mean	standard deviation
pH	7.6	7.5	7.4	7.2	7.1	6.9	7.28	0.26
Temp (degrees)	24	20.1	18	23.1	25	29	23.2	3.85
BOD (mg/l)	250	240	260	240	248	224	243.66	12.16
COD (mg/l)	600	384	528	736	672	640	593.33	123.97
MPN(Total COLIFORM)/100ml (natural log numbers)	16.5	16.9	17.2	17.2	14.8	14.69	16.6	16.33
TSS (mg/l)	354	372	396	464	396	412	399	37.85
Turbidity (NTU)	39	68.7	72	270	141	152	123.78	84.11
Acidity (mg/l as CaCo3)	26	50	50	60	48	55	48.16	11.7
Alkalinity (mg/l as CaCo3)	120	450	520	540	565	600	465.83	176.7
Total phosphorous (mg/l)	1.62	0.8	0.21	0.08	1.8	2.1	1.1	0.85
Sulphates (mg/l)	41	69.3	44.87	120	100.8	42	69.66	33.77
Chlorides (mg/l)	144.9	153.8	212.7	241.06	188	194.9	189.22	36.03
Organic Nitrogen (mg/l)	1.96	2.24	1.12	2.07	1.9	1.02	1.71	0.51
Ammonical nitrogen (mg/l)	32	11.42	29.5	31.64	22.07	17.86	24.08	8.39

Sulphide (mg/l)	6.8	35.6	12.2	6	22.4	26	18.16	11.79
Faecal coliform/100ml (natural log numbers)	15.5	16.6	16.6	16.4	13.3	13.1	16.02	15.87

Table 5.2: Parameters analysed and results for UASB outlet

Parameters	November	January	February	March	April	May	Mean	Standard deviation
pH	7.5	7.5	7.5	7.4	6.9	7	7.3	0.27
Temp (degrees)	25	20.2	18.5	23.2	26	30	23.81	4.15
BOD (mg/l)	175	141	110	125	122	115	131.33	23.87
COD (mg/l)	236	288	228	312	305	288	276.16	35.57
MPN(Total COLIFORM)/100ml (ln)	14.69	16.64	16.64	16.7	13.03	12.7	16.03	16
TSS (mg/l)	180	144	194	252	154	162	181	39.16
Turbidity (NTU)	15	42.3	34	84.6	52.1	58.5	47.75	23.59
Total phosphorous(mg/l)	1.71	0.88	0.28	0.22	2.1	2.5	1.28	0.96
Organic Nitrogen (mg/l)	1.52	2.072	1.08	2.1	1.77	0.45	1.49	0.63
Ammonical nitrogen (mg/l)	28.4	15.34	27.1	28.2	17.9	15.8	22.12	6.4
Sulphide (mg/l)	4.1	3.4	5.6	4	14.6	18	8.28	6.34
Faecal coliform/100ml (ln)	14.64	16.38	15.89	15.89	12.64	12.34	15.48	15.45

Table 5.3: Parameters analysed and their results for Polishing Pond

Parameters	November	January	February	March	April	May	Mean	Standard deviation
pH	7.5	7.6	7.7	7.3	7	6.9	7.33	0.32
Temp (degrees)	21	17	17.8	23.1	24	28	21.81	4.11
BOD (mg/l)	38	68	45	48	30	36	44.16	13.33
COD (mg/l)	165	192	132	96	168	184	156.16	36

MPN(Total COLIFORM)/100ml (ln)	14.34	15.88	15.42	15.89	7.93	6.19	15.14	15.12
TSS (mg/l)	42	48	52	45	52	48	47.83	3.92
Turbidity (NTU)	11.81	14.4	10	9.2	18.6	21.1	14.18	4.8
Total phosphorous (mg/l)	1.8	0.92	0.31	0.21	2.22	2.66	1.35	1.02
Organic Nitrogen (mg/l)	0.95	1.109	1.03	2.06	1.35	0.1	1.09	0.63
Ammonical nitrogen (mg/l)	25.2	27.8	25	26.9	14.88	11.4	21.86	6.92
Sulphide (mg/l)	2.9	1.6	1.4	3.2	6.7	8	3.96	2.74
Faecal coliform/100ml (ln)	14.15	15.4	14.64	15.42	7.37	4.86	14.63	14.62

Table 5.4: Parameters analyzed and results for Chlorination unit

Parameters	November	January	February	March	April	May	Mean	Standard deviation
pH	7.4	7.6	7.6	7.4	7.2	7.1	7.38	0.2
Temp (degrees)	21.5	17.1	17.7	23	24	28.5	21.96	4.24
BOD (mg/l)	32	51	32	41	28	34	36.33	8.35
COD (mg/l)	122	128	116	80	156	176	129.6	33.33
MPN(Total Coliform)/100ml (ln)	13.91	13.57	14.91	15.89	7.24	5.13	14.58	14.93
TSS (mg/l)	36	44	48	48	46	46	44.66	4.5
Turbidity (NTU)	13.54	15	8	7.54	18	20.7	13.79	5.28
Acidity (mg/l as CaCo3)	30	48	30	50	35	40	38.83	8.72
Alkalinity (mg/l as CaCo3)	118	550	480	570	460	500	446.33	166.15
Total phosphorous (mg/l)	1.82	1.1	0.32	0.27	2.37	2.8	1.44	1.05
Sulphates (mg/l)	43.9	41.2	35.6	82	75.3	34	52	21.06
Chlorides (mg/l)	160.3	183.6	250	276.51	210	265.8	224.36	47.04
Organic Nitrogen (mg/l)	0.84	0.952	1.01	2.04	1.28	0	1.02	0.66
Ammonical nitrogen (mg/l)	24	28.72	25.2	26.2	14.3	11.09	21.58	7.13
Sulphide (mg/l)	2	1.3	0.4	3.1	5.9	7.2	3.31	2.68
Faecal coliform/100ml(ln)	12.7	15.4	14.34	13.12	6.84	4.7	14.5	14.68

5.2 Statistical analysis of results

Graphs and tables representing values of wastewater parameters at various locations of STP are shown in this section.

Table 5.5: Mean values of BOD, COD, TSS at various locations of STP

Location	BOD (mg/l)	COD (mg/l)	TSS (mg/l)
Inlet	243.6	593.3	399
UASB	131.3	276.1	181
Polishing pond	44.1	156	47.8
Chlorination unit	36.3	129.6	44.6

Note: All the parameter values used are the mean values observed during six months study period

It was found that BOD value at STP outlet was not complying with the discharge standards. It may be due to the ineffective chlorination (existing dose is 8 ppm); on the other hand in terms of COD and TSS; discharge standards were met and the treatment process turned out to be efficient.

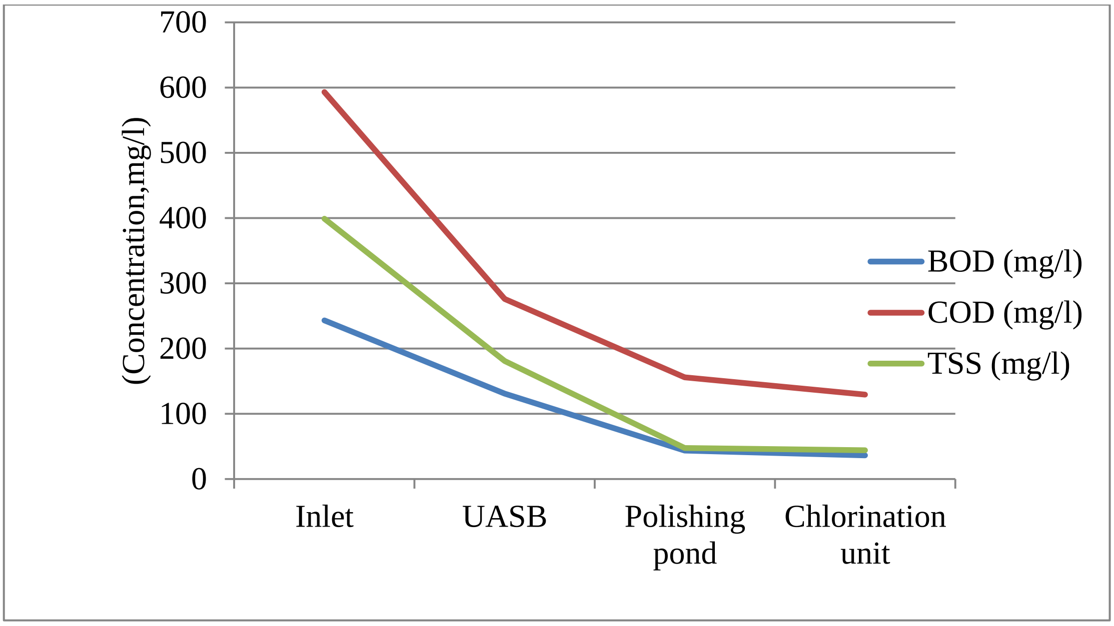

Figure 5.1: Removal trend of BOD, COD, TSS at various locations of STP

During our six months study of the STP, it can be observed from the table and corresponding graph that BOD removal efficiency of UASB reactor, Polishing pond, and chlorination unit was 46.1%, 66.4% and 17.6% respectively. COD removal efficiency was 53.4%, 43.5%, 16.9% respectively. Similarly, TSS removal efficiency of UASB reactor, polishing pond and chlorination unit was 54.6%, 73.5% and 6.6% respectively.

Table 5.6: Coliform count mean values at various locations of STP

Location	MPN(Total Coliform)/100ml (ln)	MPN(Faecal coliform)/100ml (ln)
Inlet	16.6	16.02
UASB	16.03	15.48
Polishing pond	15.14	14.63
Chlorination unit	14.58	14.5

Note: All the parameter values used are the mean values observed during six months study period

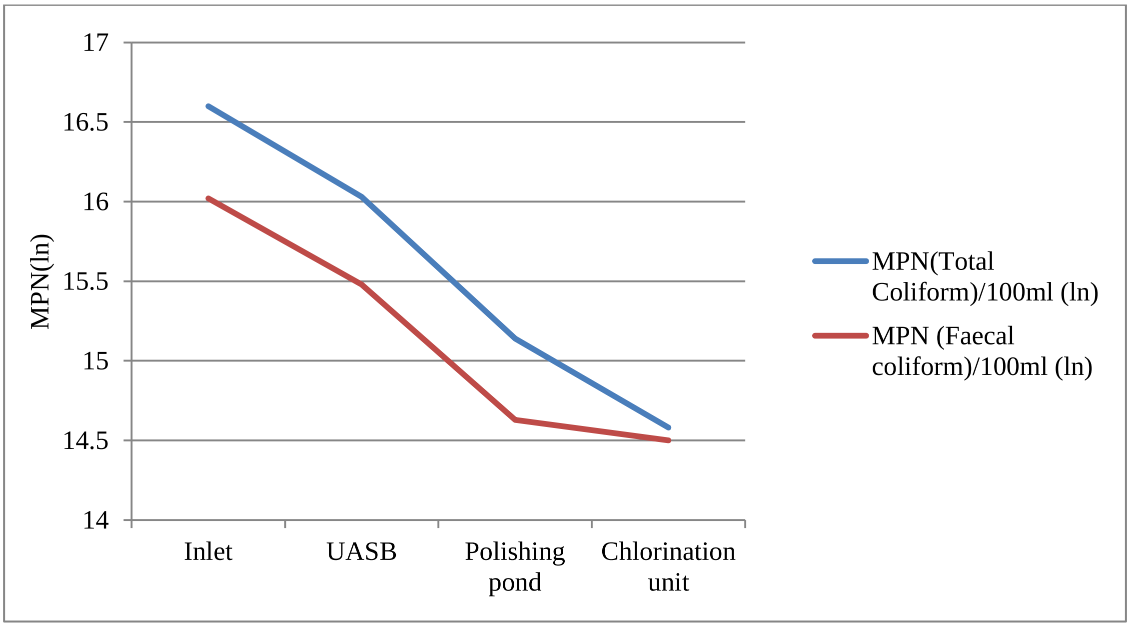

Figure 5.2: Coliform count at various sampling locations

Total coliform removal efficiency in UASB reactor, polishing pond and chlorination unit was 46.5%, 59% and 42.9% respectively and fecal coliform removal was 41.5%, 57.2% and 12.2% respectively (Table 5.6).

Table 5.7: TKN, Total phosphorous values at various locations of STP

Location	TKN (mg/l)	Total P (mg/l)
Inlet	25.7	1.1
UASB	23.5	1.3
Polishing pond	22.8	1.3
Chlorination unit	11.09	1.4

Note: All the parameter values used are the mean values observed during six months study period

From the above table it can be concluded that TKN and Total- Phosphorous values were in compliance with the discharge standards.

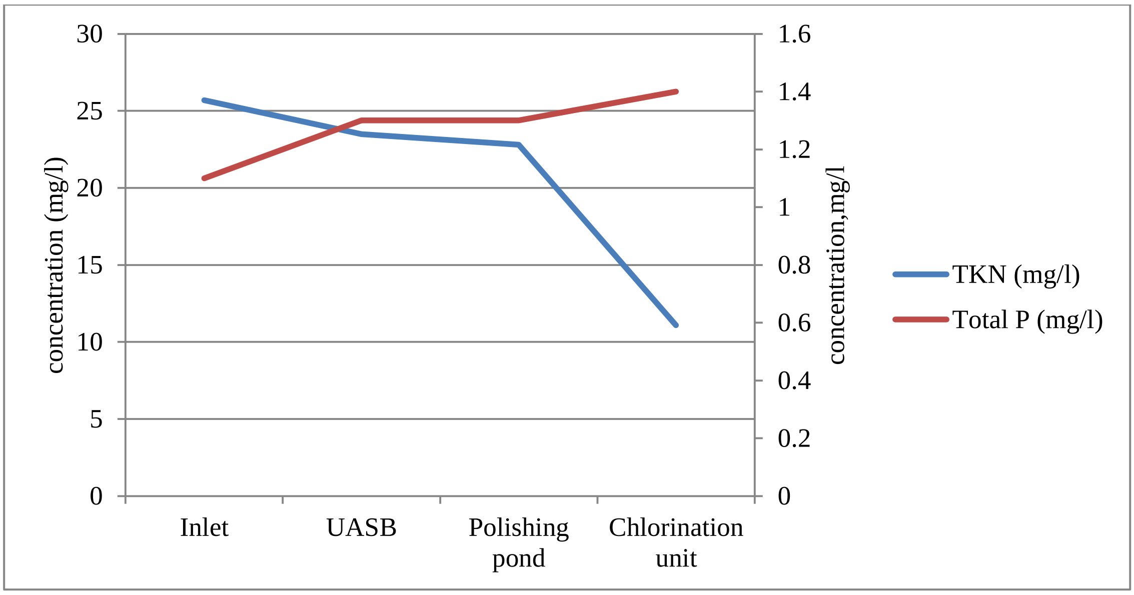

Figure 5.3: TKN and Total P removal trend at STP

From the above graph it can be seen that TKN values get reduced at STP while Total –P was not significantly reduced, however both TKN and Total –P values were in compliance with discharge standards.

Table 5.8: Removal patterns of chlorides, sulphates and sulphides

Location	Chlorides (mg/l)	Sulphates (mg/l)	Sulphides (mg/l)
Inlet	189.2	69.6	18.1
Chlorination unit (final outlet)	224.3	52	3.3

Note: All the parameter values used are the mean values observed during six months study period

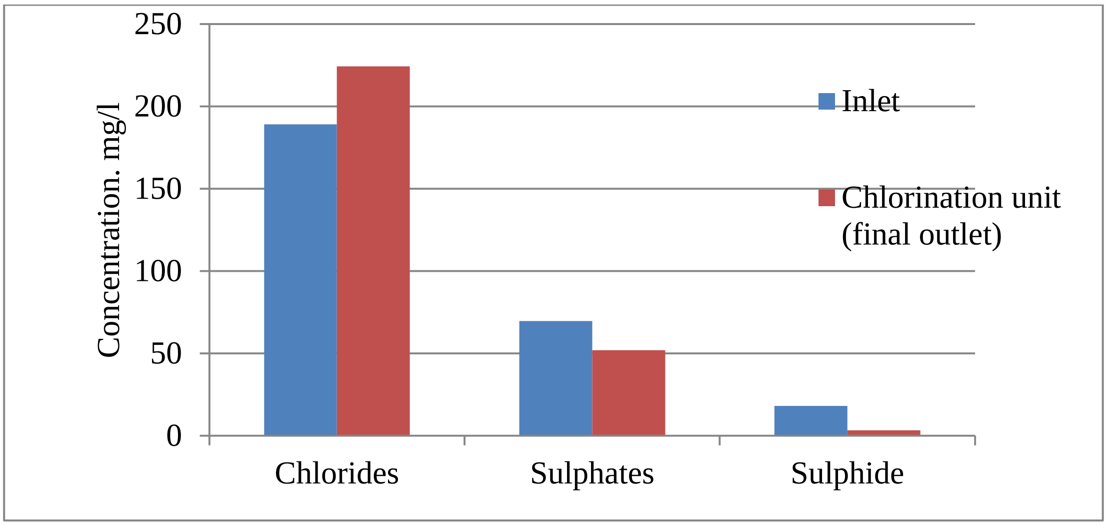

Figure 5.4: Chloride, sulphate, sulphide values at Inlet and Outlet

Sulphate and sulphide removal in the sewage treatment plant was 25.2% and 81.8% respectively while chloride concentration was found to be increased at outlet.

5.3 Design analysis

The results obtained by the actual sampling and analysis were effectively used in addressing the optimal design conditions existing for the STP. Removal efficiencies were studied for the following design parameters.

Table 5.9: STP Units along with the design parameters

UASB	COD, Coliform count, TSS
Polishing Unit	BOD surface loading rate, Ammonical nitrogen, Coliform count
Chlorination unit	Coliform count

5.3.1 Treatment efficiency of UASB reactors:

- COD removal efficiency = $[(COD_{in} - COD_{out})/COD_{in}]*100$ (5.1)

Table 5.10: COD removal efficiencies during sampling period

Month	COD removal Efficiency (%)
November	60.6
January	25
February	56.8
March	57.6
April	54.6
May	55

- **COD (E) = 100(1-0.68*HRT $^{(-0.35)}$)** (5.2)

  The above equation can be written as; Log (1-E/100) = Log x + y Log (HRT), where x = 0.68, y = -0.35

  Regression Analysis: COD (E) versus Temp, HRT

Table 5.11: Regression Analysis COD (E) versus Temp, HRT

COD (E)	Temp	HRT
67	24	7.92
66.5	20.1	7.61
66.8	18	7.79
67.2	23.1	8.05
66.2	25	7.38
66.3	29	7.49

The regression equation is:

COD (E) = 54.9 - 0.00146 Temp + 1.53 HRT (5.3)

R-Sq = 99.7%

Regression equation developed from the actual analysis of results yielded equation with R-Sq value greater than 99 % showing that the COD value can reliably be predicted with accuracy knowing the two parameters of Temperature and HRT.

- To validate equation (2), the above equation can be written as;

  Log (1-E/100) = Log x + y Log (HRT), where x = 0.68, y = -0.35. Here we will use various values of (E) and corresponding HRT values and solving simultaneous equations for x and y, we get mean values of x and y. We get, x = 1.99 and y = -0.74

  Therefore, new equation comes out to be:

  $E_{COD} = 100(1-1.99*HRT^{(-0.74)})$ (5.4)

  Hence for the studied conditions the new equation developed will yield more reliable results than the general equation available.

- **TSS removal efficiency**

  Measured TSS removal efficiency = $[(TSS_{in} - TSS_{out})/TSS_{in}]*100$ (5.5)

Table 5.12: TSS removal efficiencies

Month	TSS removal Efficiency (%)
November	49
January	61.2
February	51
March	45.7
April	61.1
May	60.6

TSS removal efficiency is related with HRT and given by;

TSS removed, TSS (E) = $102*HRT^{(-0.2)}$ (5.6)

Equation (1) can be used to find TSS removal efficiency of UASB reactor at various HRTs obtained during our six month sampling period.

- **Regression Analysis: TSS (E) versus Temp, HRT, chloride**

  The regression equation comes out to be;

  TSS (E) = 77.6 + 0.00217 Temp - 1.98 HRT + 0.000741 chloride (5.7)

  R-Sq = 100.0%

  Regression analysis undertaken yield good results in terms of R-sq values suggesting that the predicted equation can reliably be used for estimating the TSS.

Table 5.13: TSS (E) regression analysis w.r.t. Temp, HRT and chlorides

TSS (E)	Temp	HRT	Chloride
62	24	7.92	144.9
62.6	20.1	7.61	153.8
62.3	18	7.79	212.7
61.8	23.1	8.05	241.06
63.1	25	7.38	188
62.9	29	7.49	194.9

- To validate equation (1), the above equation can be written as;
  Log TSS (E) = Log x + y Log (HRT), where x = 102, y = -0.24

  Here we will use various values of TSS (E) and corresponding HRT values and solving simultaneous equations for x and y, we get mean values of x and y.

  We get, x = 104.5 and y = -0.26.Therefore, new equation comes out to be:

  $$TSS\ (E) = 104.5 * HRT^{(-0.26)} \qquad (5.8)$$

- **TSS (E) and HRT correlation:**
  Pearson correlation of TSS (E) and HRT = -0.998
  P-Value = 0.000. P value less than 0.05 shows direct relationship of TSS and HRT.

- **Analysis of UASB reactors based upon MPN (Faecal Coliform) count:**

Table 5.14: MPN reduction observed/100ml (UASB reactor)

Month	MPN at UASB inlet	MPN at UASB outlet	Reduction in MPN
November	54,00,000	23,00,000	31,00,000
January	170,00,000	130,00,000	40,00,000
February	170,00,000	80,00,000	90,00,000
March	140,00,000	80,00,000	60,00,000
April	630,000	3,10,000	320,000
May	490,000	2,30,000	260,000

- MPN estimation by using empirical relation:
  $$N_{anaerobic}(\text{per 100 ml}) = N_{raw}/(1+K_{B(T)}.\Theta_{UASB}) \qquad (5.9)$$

where $K_{B(T)} = 2.6(1.19)^{T-20}$, Θ_{UASB} = HRT(days).$K_{B(T)}$ can be calculated for various months using equation (5.9).

Table 5.15: $K_{B(T)}$ for different months

Month	$K_{B(T)}$	Θ_{UASB}(days)
November	4.08	0.33
January	0.96	0.32
February	3.5	0.32
March	2.2	0.34
April	3.3	0.31
May	3.6	0.31

Equation; $K_{B(T)} = 2.6(1.19)^{T-20}$ can be written as $K_{B(T)} = x(y)^{T-20}$. Using above values of $K_{B(T)}$ and T, we calculated, x and y values for validating the said equation. The predicted x and y values obtained were 2.77 and 1.02 respectively. Therefore the new postulated equation can be stated as $K_{B(T)} = 2.77(1.02)^{T-20}$. This equation can yield more reliable estimated results.

Table 5.16: $K_{B(T)}$ and Temp. (^{0}C) values for UASB reactor

$K_{B(T)}$	Temp. (^{0}C)
4.08	25
0.96	20.2
3.5	18.5
2.2	23.2
3.3	26
3.6	30

- **Regression Analysis: $K_{B(T)}$ versus Temp. (^{0}C)**

The regression equation is: $K_{B(T)}$ = 0.272 Temp. – 4.265

R-sq value for the above equation is 0.90, which indicates the linear relationship between $K_{B(T)}$ and Temperature. Hence the above regression equation can reliably be used in predicting one of the variables knowing the other variable.

5.3.2 Analysis of polishing pond based upon MPN (Faecal Coliform) count

Table 5.17: MPN reduction observed/100ml (polishing pond)

Month	MPN at P.P inlet	MPN at P.P outlet	Reduction in MPN
November	23,00,000	14,00,000	9,00,000
January	130,00,000	49,00,000	81,00,000
February	80,00,000	23,00,000	57,00,000
March	80,00,000	50,00,000	30,00,000
April	3,10,000	1600	3,08400
May	2,30,000	130	2,29,870

- **MPN estimation by using empirical relation;**

  $N_{anaerobic}$(per 100 ml) = $N_{raw}/(1+K_{B(T)}.\Theta_{UASB})$; where $K_{B(T)} = 2.6(1.19)^{T-20}$, Θ_{UASB} = HRT(days),T = Temperature (mean value) and Θ_{UASB}= 1.83 days.

  We get, $N_{anaerobic}$(per 100 ml) = 7,00,087. Here mean value of N_{raw} was taken.

- **Design analysis on the basis of BOD surface loading rate:**

  Surface loading rate is given by;

  $$\lambda_s = 350(1.107 - 0.002T) \tag{5.10}$$

  $\lambda_s = 287.5$(Kg/ hec. per day of BOD)

  we know, λ_r is removal rate (kg/hec. per day of BOD)

  $$\text{Therefore, } \lambda_r = (0.79 * \lambda_s) + 2 \tag{5.11}$$

  $\lambda_r = 229.1$(kg/hec. per day of BOD), Average Flow rate =126500 (m^3/day)

  Influent BOD of pond =131.3(mg/l)

  = 16609.45(Kg BOD/17 hectare/day)

  =977(Kg/hectare/day)

  Effluent BOD of pond = 44.16(mg/l) =328.6(Kg BOD/hec/day)

  Removal rate = Influent BOD – Effluent BOD = 648.4(Kg BOD/hec/day)

- **Analysis of Chlorination unit based upon MPN (Faecal Coliform) count**

Table 5.18: MPN reduction observed/100ml (Chlorination unit)

Month	MPN at chlorination inlet	MPN at Chlorination unit outlet	Reduction in MPN
November	14,00,000	3,30,000	10,70,000
January	49,00,000	49,00,000	Nil
February	23,00,000	17,00,000	6,00,000
March	50,00,000	50,00,000	Nil
April	1600	940	660
May	130	110	20

It was found that chlorination dose of 8 ppm was not effective as coliform count was out of limits with respect to discharge standards. Even in the sample analysis no residual chlorine was detected.

Chapter 6
Conclusion

The proposed research work was planned to assess the performance and design analysis of UASB based Sewage Treatment Plant. Monthly analysis of STP samples (obtained from selected locations) was performed over six months and compliance of results with the regulatory standards was checked. In the second task, design analysis of UASB reactors and polishing ponds, actual performance of the STP against the design or expected performance was compared.

According to the empirical formulas the UASB was supposed to remove COD, BOD and TSS by 70%, 75% and 80% respectively, while the actual removal efficiencies observed in this study for these three parameters were 53.4%, 46.1% and 54.6%. Similarly, the polishing pond was supposed to have COD, BOD and TSS removal efficiencies of 55%, 40% and 50% respectively. But the actually observed efficiencies for these parameters were 43.5%, 66.4% and 73.5% respectively.

Through regression modelling the commonly used empirical formulae for the performance assessment were calibrated and validated. The original performance assessment formulae and their calibrated versions for UASB reactor in the present study are as given below:

- Original performance assessment formula for COD removal efficiency;
  $COD\ (E) = 100(1\text{-}0.68*HRT^{(-0.35)})$
- Calibrated performance assessment formula for COD removal efficiency;
  $COD\ (E) = 100(1\text{-}1.99*HRT^{(-0.74)})$
- Original performance assessment formula for TSS removal efficiency;
  $TSS\ (E) = 102*HRT^{(-0.2)}$
- Calibrated performance assessment formula for TSS removal efficiency;
  $TSS\ (E) = 104.5*HRT^{(-0.26)}$
- Original performance assessment formula for first-order rate constant for FC removal;
  $K_{B(T)} = 2.6(1.19)^{T-20}$

- Calibrated performance assessment formula for first-order rate constant for FC removal;

  $K_{B(T)} = 2.77(1.02)^{T-20}$

Overall COD, BOD and TSS removal efficiencies of the STP were 78%, 85% and 88% respectively. Further, the treated effluent is most of the time complying with the applicable regulatory requirements or effluent standards. However, the coliform count (MPN) has been an exception. Ineffective chlorination could be the reason for this. Algal cells and ammonical nitrogen in the effluent of the polishing might have been increasing the breakpoint chlorination demand much beyond the actual chlorine dose of 5-8 ppm.

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