EVALUATION AND OPTIMIZATION OF SEWAGE TREATMENT PLANT (STP) PERFORMANCE AT SECTOR I-9, ISLAMABAD

By

SYEDA SUMAIRA FATIMA
2009-NUST-MSPhD-Env E-07

Institute of Environmental Sciences and Engineering (IESE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST)
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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering

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It is certified that contents and form of thesis entitled

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has been found satisfactory for the requirements of the degree.

Supervisor___________________
Dr. Sher Jamal Khan
Assistant Professor
IESE,SCEE, NUST

Co-supervisor ____________________
Dr. Zahir-ud-din Khan
Associate Professor
IESE, SCEE, NUST

Co-supervisor ____________________
Dr. Imran Hashmi
Assistant Professor
IESE, SCEE, NUST

External Examiner____________________
ShahidSohail
Director CDA

Dedicated to

My Adorable Daughter

AizahBatool

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SYEDA SUMAIRA FATIMA

Table of Contents

LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
TSS	Total Suspended Solids
MLSS	Mixed Liquor suspended Solids
MLVSS	Mixed Liquor volatile Suspended Solids
SRT	Sludge Retention Time
HRT	Hydraulic Retention Time
SOUR	Specific Oxygen Uptake Rate
SVI	Sludge Volume Index
OLR	Organic Loading Rate
F/M	Food to microorganisms ratio
ZSV	Zone Settling Velocity
MBR	Membrane Bioreactor
GSBR	Granulated Sludge Bed Reactor
DO	Dissolved Oxygen
STP	Sewage Treatment Plant

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In this study, the performance of wastewater treatment plant (WWTP) located at sector I-9 Islamabad, Pakistan, was evaluated. This full scale domestic wastewater treatment plant is based on conventional activated sludge process (CASP). The parameters which were monitored regularly included total suspended solids (TSS), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), biological oxygen demand (BOD), and chemical oxygen demand (COD). It was found that the biological degradation efficiency of the plant was below the desired levels in terms of COD and BOD. Also the plant operators were not maintaining consistent sludge retention time (SRT). Abrupt discharge of MLSS through the Surplus Activated sludge (SAS) pump was the main reason for the low MLSS in the aeration tank and consequently low treatment performance. In this study, I-9 WWTP was operated at three different SRTs of 12d, 8d and 7d and it was optimized based on desired MLSS concentration between 3000-3500 mg/L and required performance in terms of BOD, COD and TSS. Maximum removal efficiency of these parameters was found to be at 7d SRT. Based on the results obtained from the study, a steady state modeling of plant is done by using the simulation software Aquifas+. This study revealed that SRT is a very important operational parameter and its knowledge and its correct implementation by the plant operators should be mandatory.

INTRODUCTION

1.1 BACKGROUND

The objective of a Sewage Treatment Plant is to provide a regulated outflow of water with limited quantity of contaminants in order to maintain an ecologically controlled environment. This is usually done by means of diverse unit operations applied to the incoming wastewater in a sequential manner until a cleaner outflow is achieved (Peavy et al., 1985). In a typical wastewater treatment plant, the wastewater is directed through a series of physical, chemical and biological processes to remove physical, chemical and biological contaminants. Sewage treatment strategies are aimed at maximizing energy and material recovery while minimizing the final amount of emissions delivered to the environment (Zhang et al.,2010).

The most common and efficient biological treatment process is 'activated sludge', which is used for domestic and industrial wastewater treatment. This process is employed extensively throughout the world both in its conventional and modified forms, all of which are capable of meeting secondary treatment effluent limits.

In a sewage treatment plant (STP), the activated sludge process is used for one or several of the following purposes:

- Oxidizing carbonaceous matter i.e., biological matter
- Oxidizing nitrogenous matter
- Removing phosphates
- Driving off entrained gases e.g., carbon dioxide, ammonia, nitrogen, etc
- Generating a biological floc, that is easy to settle
- Generating a liquor, low in dissolved or suspended material

Edward Arden and W.T. Lockett, while conducting research for the Manchester Corporation Rivers Department at Davyhulme Sewage Works, developed the activated sludge process in 1913 in UK. In the activated sludge process, microorganisms are mixed thoroughly with organic material in the wastewater so that the microorganisms grow by using the organics as food. As the microorganisms grow, and are mixed by the agitation of the air, the individual organisms clump together (flocculate) to form an active mass of microbes called “activated sludge”.

The activated sludge process (ASP) consists of an equalization basin, an aeration tank, a secondary clarifier and a sludge recycle line. Raw wastewater is homogenized in an equalization basin to reduce variations in the feed, which may cause process upsets of the microorganisms and diminish treatment efficiency. The aeration tank brings organic matter containing wastewater, aerobic bacteria and dissolved oxygen into contact so that biological oxidation breaks the organic matter down into carbon dioxide and water. The wastewater/aerobic bacteria flow is kept mixed and aerated by air blown in through diffusers. The mixed liquor is discharged continuously from the aeration tank into a secondary clarifier.

Environmental engineers and scientists develop collection and treatment systems to carry waste material away from where people live and produce the waste, and discharge it into the environment. In developed countries, substantial resources are applied to the treatment and detoxification of this waste before it is discharged into a river, lake, or ocean system. Developing nations are striving to obtain the resources to develop such systems so that they can improve water quality in their surface waters and reduce the risk of water-borne infectious disease.

Like other developing countries, public and private wastewater disposal systems in Pakistan are very deficient or even missing. Water sanitation is a major problem in Pakistan and public awareness regarding the issue is least. The Ministry of Water and Power, Pakistan reported in 2002 that only 1% of the domestic and industrial wastewater receives treatment. Considering the needs of the nation, a state-of-the-art sewage treatment plant has recently been established at Sector I-9, Islamabad employing Conventional Activated Sludge Process (CASP) for treatment. This is for the first time in the country that such a large-scale sewage treatment plant is established. This Rs 2.72 billion plant is capable of treating 17 million gallons of sewage per day (Daily Times, 2009).

According to Metcalf and Eddy, 1991, the success of any municipal wastewater plant depends mainly on the expertise of both the designers and the operators of the plant.For making WWTPs effective, it is pertinent to monitor their performance on a regular basis. The organic pollution indicator variables such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ammonium nitrogen (NH_4–N) are considered as the key parameters for describing the wastewater characteristics and their corresponding ratio in the effluent to influent wastewater as a measure of the overall performance for a conventional WWTP (Singh et al., 2009). Other parameters that need to be monitored on daily basis to ensure satisfactory performance of the plant include organic loading rate (OLR), sludge retention time (SRT), hydraulic retention time (HRT), food to microorganisms (F/M) ratio, nutrient removal etc.

This treatment plant located at sector I-9 Islamabad is facing many challenges at present. Most of the sewerage lines, the large truck-lines and the tributaries of the city are partially broken and the existing infrastructure of pipelines is too old. As a result, most of the sewage of the city remains untreated. This treatment plant is under operating at present because only a portion of sewage generated in the city reaches the plant for treatment due to inadequate infrastructure. The sewage that does get through is highly diluted, suggesting mixing with fresh water from leaking pipes or general percolation. A correct waste management policy should be based on the principles of sustainable development, according to which refuse is not simply regarded as something to eliminate but rather as a potential resource to be recycled (Marchettini et al., 2007). However, the effluent of this treatment plant is discharging into Lehnullah, instead of using it for landscaping, ground water recharge and other purposes.

In this context, the aim of this study is to identify and investigate the issues concerning the I-9 Sewage Treatment Plant performance and to suggest feasible solutions to mitigate them. Different parameters will be analyzed during the study including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), sludge retention time (SRT) and hydraulic retention time (HRT). Since this treatment plant is receiving much less amount of the sewage for which it is designed, special attention would be given to reduce the operational cost of the plant. Aquifas+ software will be used to optimize the performance efficiency of the plant. It is expected that the results of thesis will be helpful in optimizing the plant’s performance.

Activated sludge modelling and simulation are widely applied. Learning, design and process optimization are the main application areas of WWTP models (Gernaey et al., 2004). Aquifas+ is the extension and enhancement of IWA-ASM2d model. It is a Microsoft. NET based application, which uses sophisticated numerical analytic technique to solve the system of non-linear model mass balance equations (Sen and Lodhi, 2010).

1.2 OBJECTIVES OF STUDY

The main objectives of this study are to:

- Evaluate the treatment performance of I-9 Sewage treatment plant.
- Optimize the operating conditions prevailing at present at I-9 Sewage Treatment Plant.
- Steady state modelling of I-9 STP by using wastewater treatment software (Aquifas+).

1.3 SCOPE OF STUDY

The scope of the study includes

- Treatment performance evaluation of a full-scale Sewage treatment plant located at sector I-9, Islamabad.
- Real wastewater coming, from different sectors of Islamabad will be analyzed at the influent, different treatment stages and the effluent.
- Physical, organic and inorganic constituents of wastewater will be analyzed at I-9 STP laboratory as well as at IESE laboratories, NUST, H-12

LITERATURE REVIEW

2.1 WASTEWATER TREATMENT

Sewage treatment or domestic wastewater treatment is the process of removing contaminants from wastewater and household sewage. It includes physical, chemical, and biological processes to remove the respective contaminants. The objective of sewage treatment is to produce an environmentally-safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse. Conventional sewage treatment may involve below mentioned three stages.

- **Primary treatment:** It consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.
- **Secondary treatment:** It removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- **Tertiary treatment:** The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.).

2.1.1 Objective of Wastewater Treatment

The primary objective of wastewater treatment is to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment.

2.1.2 Wastewater Treatment Plants

Wastewater treatment plants play an important role in the abatement of water pollution. They protect the public from disease causing bacteria and viruses by disinfecting the wastewater. They clean the waste stream by removing solids, reducing organic matter and pollutants, and by restoring oxygen (Spellman and Drinan, 2003).

2.2 BIOLOGICAL WASTEWATER TREATMENT

With proper analysis and biological control, almost all wastewaters containing biological constituents can be treated biologically. The purpose of biological treatment of wastewater is to reduce its BOD (Biological Oxygen Demand) content.

2.2.1 Objectives of Biological Wastewater Treatment

The overall objectives of biological treatment of domestic wastewater are to:

1. Transform (i.e., oxidize) dissolved and particulate biodegradable constituents into acceptable end products
2. Capture and incorporate suspended and non-settle able colloidal solids into a biological floc or biofilm
3. Transform, or remove nutrients such as nitrogen and phosphorus and,
4. In some cases, remove specific trace organic constituents and compounds

2.2.2 Types of Biological Processes for Wastewater Treatment

The principal biological processes used for wastewater treatment can be divided into two main categories:

1. Attached growth (or biofilm) processes
2. Suspended growth processes

2.2.2.1 Attached Growth Processes

In attached growth processes, the microorganisms responsible for the conversion of organic material or nutrients are attached to an inert packing material. The organic material and nutrients are removed from the wastewater flowing past the attached growth also known as biofilm. Packing materials used in attached growth processes include rock, gravel, slag, sand, redwood, and a wide range of plastic and other synthetic materials. Attached growth processes can also be operated as aerobic or anaerobic processes. The packing can be submerged completely in liquid or not submerged, with air or gas space above the biofilm liquid layer. The most common aerobic attached growth process used is trickling filter.

2.2.2.2 Suspended Growth Processes

In suspended growth processes, microorganisms responsible for treatment are maintained in liquid suspension by appropriate mixing methods. The most common suspended growth process used for municipal wastewater treatment is the activated sludge process.

2.3 INTRODUCTION TO ACTIVATED SLUDGE PROCESS

The activated sludge process is the most widely applied biological wastewater treatment process (Doorn et al., 2006 and Okoh et al., 2007). In the activated sludge process, a bacterial biomass suspension (the activated sludge) is responsible for the removal of pollutants. Activated sludge system has been widely used throughout the world. (Healey, 1989) reported that there are 9000 US, 501 UK and over 60 French wastewater treatment plants employing activated sludge process.

2.3.1 Process Description

The activated sludge process involves blending settled primary effluent wastewater with a culture of microorganisms into a fluid termed "mixed liquor". This mixed liquor is passed through aeration tank which provides an adequate oxygen source for the microorganisms to break down the organic pollutants. In all activated sludge plants, once the wastewater has received sufficient treatment, excess mixed liquor is discharged into settling tanks and the treated supernatant undergoes further treatment before discharge. Part of the settled material, the sludge, is returned to the head of the aeration system to re-seed the new wastewater entering the tank. This fraction of the sludge is called return activated sludge (RAS.). Excess sludge is called surplus activated sludge (SAS) or waste activated sludge (WAS). WAS is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. WAS is stored in sludge tanks and is further treated by digestion, either under anaerobic or aerobic conditions before disposal. The schematic of activated sludge process is shown in Figure 2.1.

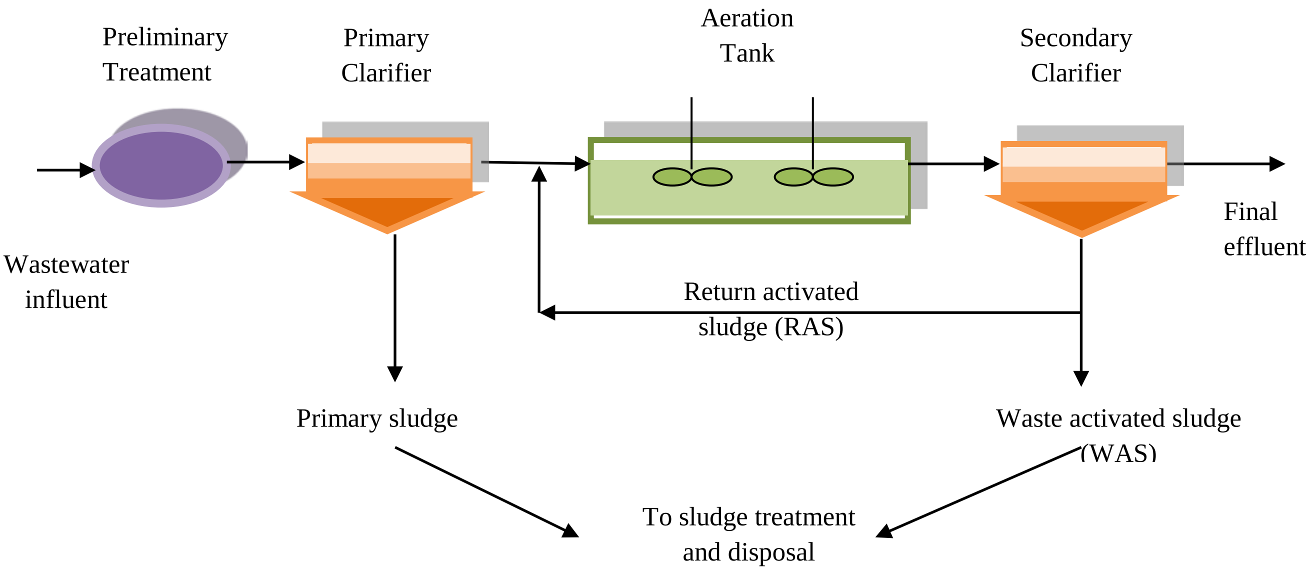

Figure 2.1: Activated Sludge Wastewater Treatment Flow Diagram

2.3.2 Recent Process Developments

In the last few decades significant developments have been made in the design and operation of activated sludge systems e.g., incorporation of nutrient removal, improvement of effluent quality, reduction of aeration cost and reduction of sludge separation problems (Van Haandel and Van der Lubbe, 2007). Several new configurations of the activated sludge process have been developed which include

2.3.2.1 Membrane Bioreactor (MBR):

A modification of the conventional activated sludge system in which the final settler is replaced by micro or ultra-filtration membranes that retain all suspended solids, allowing only the clean effluent (permeate) to pass.

2.3.2.2 Aerobic Granulated Sludge Bed Reactor (GSBR):

A modification of the conventional activated sludge system in which, by the application of specific operational conditions, a granulated sludge is obtained that settles extremely well.

2.4 PROCESS MICROBIOLOGY

To design and operate an activated-sludge system efficiently, it is necessary to understand the importance of the microorganisms in the system. In nature, the key role of the bacteria is to decompose organic matter produced by other living organisms. In the activated-sludge process, the bacteria are the most important microorganisms because they are responsible for the decomposition of the organic material in the influent. In the reactor, or mixed-liquor tank, a portion of the organic waste matter is used by aerobic and facultative bacteria to obtain energy for the synthesis of new cells. In general, the bacteria in the activated-sludge process are gram-negative and include members of the genera *Pseudomonas*, *Zoogloea*, *Achrombacter*, *Flavo bacterium Nocardia*, *Bdellovibrio*, *Mycobacterium*, and the two nitrifying bacteria *Nitrosomonas* and *Nitrobacter*. Additionally, various filamentous forms, such as *Sphaerotilus*, *Beggiatoa*, *Thiothrix*, *Lecicothrix*, and *Geodichum*, may also be present. While the bacteria are the microorganisms that actually degrade the organic waste in the influent, the metabolic activities of other microorganisms are also important in the activated-sludge system. For example, protozoa and rotifer act as effluent polishers. Protozoaconsume dispersed bacteria that have not settled.

2.5 CRITICAL FACTORS AFFECTING ACTIVATED SLUDGE PROCESS

2.5.1 Sludge Retention Time (SRT)

The solids retention time (SRT) is one of the most important parameters for the design of WWTPs, relating to growth rate of microorganisms and to effluent concentrations. The SRT or sludge age, indicates the mean residence time of microorganisms in the reactor. Only organisms which are able to reproduce themselves during this time can be detained and enriched in the system (Claraa et al., 2004). For consistent wastewater treatment, SRT must be controlled at a level that oxidizes pollutants, e.g. nitrifies, while providing "bugs" that flocculate and settle.

2.5.2 Food-to-Microorganisms (F/M) ratio

The F/M ratio also termed as sludge-loading ratio is an important feature of the aeration tank, which is needed in the operation of activated sludge process.

It is necessary that proper F/M ratio is maintained in the aeration tank in order to have an optimum operation by the activated sludge bacteria. When the F/M ratio is high, microorganisms are in log growth phase, which is characterized by excess food and maximum rate of metabolism. However, at low F/M ratio, the metabolic activity is in endogenous phase where the rate of metabolism by wastewater microorganism is low. The large mass of waste microorganisms present then competes for the relatively smaller amount of food available in the influent, and under aerobic conditions rapidly flocculates to settle out of solution by gravity. As such, BOD removal efficiency is quite high in the endogenous phase.

2.5.3 Organic Loading Rate (OLR)

The volumetric organic loading rate (OLR) is defined as the amount of BOD or COD applied to the aeration tank volume per day. Organic loadings expressed in kg BOD or COD/m^3.d may vary from 0.3 to more than 3 (Metcalf and Eddy, 2003). Higher volumetric organic loadings generally require higher oxygen transfer rates per unit volume for the aeration system.

2.5.4 Mixed Liquor Settling Characteristics

Two commonly used measures developed to quantify the settling characteristics of activated sludge are the Sludge Volume Index (SVI) and Zone Settling Velocity (ZSV).

2.5.4.1 Sludge Volume Index (SVI)

The SVI is the volume of 1 g of sludge after 30 min of settling. The SVI is determined by placing a mixed liquor sample in a 1-to 2- L cylinder and measuring the settled volume after 30 min and the corresponding MLSS concentration. The numerical value is computed using the following expression:

$$SVI = \frac{(\text{Settled volume of sludge, ml/L})\ (10^3\ \text{mg/g})}{(\text{Suspended solids, mg/L})} \qquad \text{……….Eq (2.1)}$$

2.5.4.2 Zone Settling Rate (ZSV)

The ZSV is the settling velocity of the sludge/water interface at the beginning of the sludge settleability test (Vi). The surface overflow rate based on zone settling velocity is determined using the following expression:

$$OR = \frac{(Vi)(24)}{SF} \qquad \text{…………Eq (2.2)}$$

Where OR = surface overflow rate, $m^3/m^2.d$

Vi = settling velocity of interface, m/h ($m^3/m^2.h$)

24 = conversion factor from m/h to m/d

SF = safety factor, typically 1.75 to2.5

2.6 EFFECT OF ENVIRONMENTAL CONDITIONS

2.6.1 Effect of temperature on Activated Sludge Process

Temperature has a direct effect on the SRT required for carbonaceous matter removal and especially ammonia oxidation. Bacterial growth rates increase with temperature (Stainer et al., 1986). Generally, the higher the temperature, the shorter the SRT required for biological processes (Rittmann and McCarty, 2002).

2.6.2 Effect of pH

For carbonaceous removal, pH in the range of 6.0 to 9.0 is tolerable, while optimal performance occurs near a neutral pH. It effects microbial growth i.e., bacteria dominate under neutral pH conditions (Gray, 1989).

2.6.3 Effect of DO

Oxygen is used as a final electron acceptor by aerobic microorganisms and their growth rate increases with increasing dissolved oxygen concentration. A reactor DO concentration of 2.0 mg/L is commonly used, and at concentrations above 0.5 mg/L there is little effect of the DO concentration on the degradation rate.

2.7 BIOLOGICAL NUTRIENTS REMOVAL

Biological nutrient removal from domestic and industrial wastewaters is a key factor in preventing eutrophication and is one of the most economical and efficient methods for nutrient removal (Behera et al., 2007). Nutrients in wastewater such as phosphates and nitrogen compounds stimulate the growth of algae and other photosynthetic aquatic life, which lead to accelerated eutrophication of lakes and other natural waters (Kortstee et al., 2000).

2.7.1 Nitrogen Removal

Nitrogen in domestic wastewater occurs in many forms such as organic nitrogen (protein and urea) and ammonia nitrogen. The removal of nitrogen can be achieved by two principal processes that include assimilation and nitrification-denitrification. Microorganisms assimilate ammonia nitrogen, and can be converted into cell biomass. For nitrification-denitrification, the nitrogen removal is divided into two steps. The nitrification process is performed by a group of autotrophic microorganisms. In the first step, ammonium is oxidized to nitrite by *Nitrosomonas* and nitrite is oxidized to nitrate by *Nitrobacter*under aerobic conditions. In the second step, the nitrate is converted to nitrogen gas, this being called denitrification which occurs under anoxic condition.

2.8 PROBLEMS IN ACTIVATED SLUDGE PROCESS

Many problems can develop in activated sludge operation that adversely affects effluent quality with origins in the engineering, hydraulic and microbiological components of the process. Some common of activated sludge process are listed below.

2.8.1 Poor Floc Formation, Pin Floc and Dispersed Growth Problems

Floc-forming species may grow in a dispersed and non-settleable form if the growth rate is too fast. Dispersed growth, occurs rarely in domestic waste activated sludge operation but occurs often in industrial waste treatment, generally due to high organic loading (high (F/M) ratio conditions). Here, no flocs develop and biomass settling does not occur, resulting in a very turbid effluent. The correct remedial action for a dispersed growth problem is a reduction in the F/M of the system, usually done by raising the MLSS concentration.

Dispersed growth problems often occur after a toxicity or hydraulic washout event when the activated sludge biomass is low and high F/M conditions prevail.

Small, weak flocs can be formed in activated sludge that are easily sheared and subject to hydraulic surge flotation in the final clarifier leading to a turbid effluent. These small flocs, termed pin floc, consist only of floc-forming bacteria without a filament backbone and usually are <50um in diameter. Pin floc occurs most commonly at very low F/M and long sludge age conditions. Chronic toxicity can also cause a pin floc condition.

2.8.2 Bulking Sludge

In many cases, MLSS with poor settling characteristics develops into a bulking sludge condition. It is defined as a condition in the activated sludge clarifier that can cause high effluent suspended solids and poor treatment performance. An operational definition often used is a sludge with a sludge volume index (SVI) of >150 ml/g. However, each plant has a specific SVI value where sludge builds up in the final clarifier and is lost to the final effluent, which can vary from a SVI <100 ml/g to >300 ml/g, depending on the size and performance of the final clarifier(s) and hydraulic considerations. A bulking sludge can result in the loss of sludge inventory to the effluent, causing environmental damage and effluent violations.

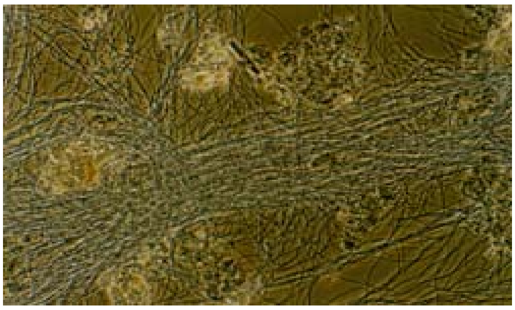

Figure 2.2: Bulking sludge in activated sludge process

2.8.3 Rising Sludge

The sludge having good settling characteristics is sometimes observed to rise or float to the surface after a relatively short settling period. The most common cause of this phenomenon is denitrification, in which nitrites and nitrates in wastewater are converted to nitrogen gas. As nitrogen gas is formed in the sludge layer, much of it is trapped in the sludge mass. If enough gas is formed, the sludge mass becomes buoyant and rises to the surface. Rising sludge problems may be overcome by

(1) Increasing the return activated sludge withdrawal rate from the clarifier to reduce the detention time of the sludge in the clarifier,

(2) Decreasing the rate of flow of aeration liquor into the offending clarifier if the sludge depth cannot be reduced by increasing the return activated sludge withdrawal rate,

(3) Increasing the speed of sludge collection mechanism in the settling tanks, and

(4) Decreasing the SRT to bring the activated sludge out of nitrification.

Figure 2.3: Rising sludge problem in activated sludge

2.8.4 Foaming

Foaming is related to the development of two bacteria genera *Nocardia* and *Micothrix* (Pitt and Jenkins, 1990), which have hydrophobic cell surfaces and attach to air bubble surfaces, where they stabilize the bubbles to cause foam.

Figure 2.4: Foaming in activated sludge process

The organisms can be found in high concentrations in the foam above the activated sludge liquid. Foaming in activated sludge process can be of different types as listed below:

Table 2.1: Description and causes of activated sludge foams

Foam Description	Cause(s)
thin, white to gray foam	low cell residence time or "young" sludge(startup foam)
white, frothy, billowing foam	once common due to non biodegradable detergents (now uncommon)
pumice-like, grey foam (ashing)	excessive fines recycle from other processes (e.g. anaerobic digesters)
thick sludge blanket on the final clarifier(s)	denitrification
thick, pasty or slimy, grayish foam(industrial systems only)	nutrient-deficient foam; foam consists of polysaccharide material released from the floc
thick, brown, stable foam enriched in filaments	filament-induced foaming, caused by Nocardia, Microthrix or type

Source: (Richard et al., 2003)

2.9 MODELLING OF FULL SCALE WWTPS

A model can be defined as the purposeful representation or description of a system of interest (Wentzel and Ekama, 1997). Models are used as a simplification of reality in such a way that they describe that part of the reality that is relevant to understand and to deal with.

Mathematical modelling of the activated sludge process provides a powerful tool for design, operational assistance, forecast future behavior and control of the process (Banadda et al., 2011; Olsson and Newell, 1999). For mathematical modelling of wastewater treatment systems, two different kinds of mathematical models are generally used: steady state and dynamic models.

2.9.1 Steady state Models

Steady state models have constant flows and loads and tend to be relatively simple. This simplicity makes these models useful for design. In these models complete description of system parameters are not required. They are oriented towards determining the more important system design parameters.

2.9.2 Steady state model calibration

In steady state model calibration, data obtained from a full scale WWTP are averaged, thereby assuming that this represents a steady state, and a simple model not including the hydraulic detail is calibrated to average effluent and sludge waste data. However, if one relies entirely on a steady state calibration some problems may be encountered since the real input variations are usually faster than the slow process dynamics that were focused upon during the steady state calibration. In other words, the process does not operate in a steady state but one still attempts to fit a steady state simplification of the model to an unsteady situation. A steady state calibration is, however, very useful for the determination of initial conditions prior to a dynamic model calibration (Pedersen and Sinkjaer, 1992).

2.9.3 Dynamic Models

Dynamic models have varying flows and loads and accordingly include time as a parameter. Dynamic models are more complex than the steady state models. These models are useful in predicting the time dependent system response of an existing or proposed system. Their complexity means that for application the system parameters need to be completely defined.

2.10 SIMULATION PROGRAMS

A wastewater treatment simulator can be described as a software that allows the modeler to simulate a wastewater treatment plant configuration. Much effort has been given to the modelling of the ASP since the early 1970s. The International Water Association (IWA) task group has been developing activated sludge models (ASMs) for many years. In 1982, the International Association on Water Pollution Research and Control (IAWPRC) established a task group on mathematical modelling for design and operation of activated sludge processes. The aim for the task group was to create a common platform that could be used for future development of models for nitrogen removal in activated sludge processes. It was the aim to develop a model with a minimum of complexity. The result was the Activated Sludge Model No. 1, ASM1 (Henze et al., 2000).

The ASM1 Model only describes reaction by heterotrophic bacteria under aerobic and anoxic conditions consuming carbonaceous substrates and autotrophic nitrifying bacteria oxidizing ammonia to nitrate. A more complex model that includes phosphorus-storing bacteria with appropriate anoxic, aerobic and anaerobic reactions has been developed and is termed as ASM2 model (Henze et al., 1995). In 1998, the Task Group decided to develop a new modelling platform, the ASM3, in order to create a tool for use in the next generation of activated sludge models. The ASM3 is based on recent developments in the understanding of the activated sludge processes, among which are the possibilities of following internal storage compounds, which have an important role in the metabolism of the organisms(Henze et al., 2000).

Today IWA models comprising ASM1, ASM2 and ASM3 have proved to be excellent tools for modelling carbon oxidation, nitrification denitrification and biological phosphorus removal processes (Gujer and Henze, 1991). The ASM based models, are included in most of today's commercial and noncommercial simulation programs. Thus, it is easy to get access to, and use the models for various purposes. These models are mainly applicable to municipal wastewater systems, but can be adapted easily to specific situations such as the presence of industrial wastewater (Gernaey et al., 2004). Despite being modified in some manner, the ASMs serve as the basis for suspended growth reactor (SGR) process modules in each of the individually developed and/or commercially available WWTP simulators (Sen and Lodhi, 2010).

2.11 MODEL APPLICATIONS

Models can serve as extremely useful tools in the design and operation of wastewater treatment plants, and in research into the behavior of these plants. For design, models can provide guidance in identifying the key design parameters and can quantify system parameters to ensure operational performance. For operations, models can provide quantitative predictions as to the effluent quality to be expected from a design or existing system, and allow the effect of system or operational modifications to be assessed theoretically. For research, models allow testing of hypothesis in a consistent and integrated fashion, to direct attention to issues not obvious from the physical system and so lead to the deeper understanding of the fundamental behavioral patterns controlling the system response (Henze et al., 2008). In this manner, models provide a framework that can guide direction for further investigations. The ASMs have been successfully applied both in research and practice and serve as the benchmark for new or expanded activated sludge models

(Morgenroth et al., 2000). Mathematical modelling of activated sludge process provides powerful tool for design, operational assistance, forecast future behavior and control of the process. GPS-X, EFOR, AQUASIM, STOAT, SSSP and WEST are among the wastewater treatment plant software packages available in the market (Daigger and Nolasco, 1995). In this study, Aquifas+ software was used to simulate the process conditions at I-9 wastewater treatment plant, Islamabad.

2.12 DESCRIPTION OF AQUIFAS+

Aquifas+ is the extension and enhancement of IWA-ASM2d model. It is a Microsoft. NET based application which uses sophisticated numerical analytic technique to solve the system of non-linear model mass balance equations (Sen and Lodhi, 2010). The software has GUI environment which allow the user to drag and drop models of different process units. The software consists of modules that can be configured and connected by flow streams to represent a specific WWTP. The modules denote different processes and operations in a wastewater treatment plant, a boundary condition (e.g., influent and effluent) or flow junctions (e.g., flow distributors and combiners).

METHODOLOGY

Full scale municipal wastewater treatment plant employing Activated Sludge Process at I-9 STP was selected for this study. The project comprised of two phases as shown below:

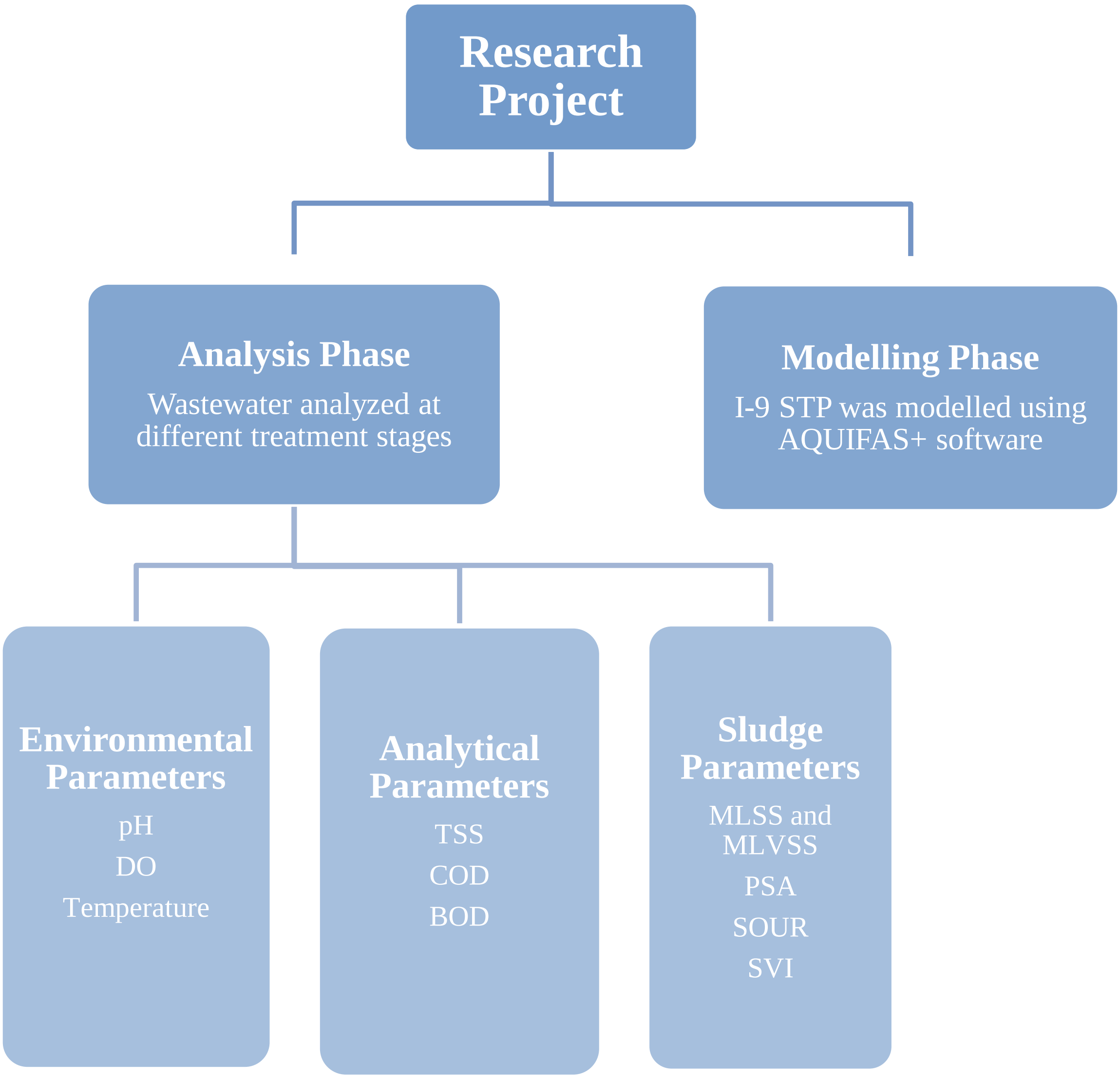

Figure 3.1: Phases of the study and the parameters analyzed

3.1 ANALYSIS PHASE

This phase started from the month of August 2010 and continued till Feb 2011. In this phase physical, organic and inorganic constituents of wastewater were analyzed.

3.1.1 Sampling Locations

In this study, treatment performance of a full scale municipal wastewater treatment plant employing Activated Sludge Process was analyzed. The organic pollution indicator variables such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ammonium nitrogen (NH_4–N) are considered as the key parameters for describing the wastewater characteristics and their corresponding ratio in the effluent to influent wastewater as a measure of the overall performance for a conventional wastewater treatment plant (Singh et al. 2009). In this study, sampling was done from the inlet, after primary clarifier, the aeration tank and outlet. The samples were collected on daily basis in clean 1 L plastic bottles and were stored in icebox maintaining a temperature of 4^oC before analyses on the same day. The list of parameters determined and the location of sampling is given in table 3.1.

Table 3.1: Parameters determined and sampling locations

S.No	Parameters	Inlet	Outlet Primary	Aeration Tank	Outlet
1	pH	✓	✓	✓	✓
2	Temperature	✓	✓	✓	✓
3	Turbidity	✓	✓		✓
4	Total Suspended Solids (TSS)	✓	✓		✓
5	Mixed Liqour Suspended Solids (MLSS) & Mixed Liqour Volatile Suspended Solids (MLSS)			✓	
6	Biological Oxygen Demand (BOD)	✓	✓		✓
7	Chemical Oxygen Demand (COD)	✓	✓		✓
8	Particle Size Distribution (PSD)			✓	
9	Specific Oxygen Uptake Rate (SOUR)			✓	
10	Sludge Volume Index (SVI)			✓	

3.1.2 Analytical Parameters and their Frequency

The analyses were performed both at I-9 STP laboratory as well as at Institute of Environmental Science & Engineering (IESE) laboratories, NUST, H-12. The parameters performed at both the locations and the frequency of analyses is presented in table 3.2.

Table 3.2: Location and frequency of analysis of different parameters

S.No	**Parameters**	**Site**		**Frequency**		
		At STP	**At IESE**	**Daily**	**Twice a week**	**Once a week**
1	pH	✓		✓		
2	Temperature	✓		✓		
3	Turbidity	▪	✓		✓	
4	Total Suspended Solids (TSS)	✓		✓		
`5	MLSS/MLVSS	✓		✓		
6	Biological Oxygen Demand (BOD)		✓			✓
7	Chemical Oxygen Demand (COD)		✓		✓	
8	Particle Size Distribution (PSD)		✓			✓
9	Specific Oxygen Uptake Rate (SOUR)		✓			✓
10	Sludge Volume Index (SVI)		✓			✓

3.1.3 Analytical Methods

The list of parameters that were analyzed, method adopted to determine each parameter and equipment/material used is reported in Table 3.3.

Table 3.3: Analytical parameters, method of analysis and equipment/material

S.No	Parameter	Method	Equipment/Material	Reference
1	Total Suspended Solids (TSS)	Filtration-Evaporation	1.2 µm glass microfiber filter (GF/C, Whatman),Oven at 105^{o}C	APHA (2005)
2	MLSS & MLVSS	Filtration-Evaporation	1.2 µm glass microfiber filter (GF/C, Whatman),Oven at 105^{o}C, Muffle Furnace at 550^{o}C	APHA (2005)
3	Chemical Oxygen Demand (COD)	Closed Reflux Titrimetric Method	COD Vials, Block heater at 150^{o}C	APHA (2005)
4	Biological Oxygen Demand (BOD)	Dilution Method	Incubation bottles	APHA (2005)
5	Total Organic Carbon (TOC)	NDIR Detection	TOC Analyzer	Rao et al., (1978)
6	Specific Oxygen uptake Rate (SOUR)	Rate of DO depletion	DO meter (YSI, Model 5100, USA)	Xing et al. (2001); Mathieu and Etienne(2000); APHA (2005)
7	Particle Size Distribution (PSD)	Laser light scattering	Particle Size Analyzer (LA-300, Horiba, Japan)	Wua et al., (2009)
8	Sludge Volume Index (SVI)	Sludge Setteleability	Imhoff Cone	Sezgina (2003)

3.1.4 COD Setup at the Plant

At I-9 STP, setup for the Closed Reflux Titrimetric method (APHA et al., 2005) was installed for COD determination. Previously, Spectrophotometric method for COD Determination was being used. In this method prepared COD Vials are used for analysis. These COD Vials are very expensive, due to which the frequency of the analysis at the plant was only twice a week. Therefore, it was suggested that the Standard Closed Reflux Titrimetric method (APHA et al., 2005) should be adopted for COD analysis instead of that Spectrophotometric method. A comparison of the cost associated with both the methods is presented in table below.

Table 3.4: Cost comparison of the two methods

COD Determination		
Closed Reflux Titrimetric Method		
S.No.	**Chemicals Required**	**Price**
1	Ferrous Ammonium SulphateHexahydrate	3400/kg
2	Sulphuric Acid	6600/2.5 liter
3	Silver Sulphate	8450/50 gm
4	Mercuric Sulphate	15750/250 gm
5	Potassium Dichromate	4095/gm
6	1,10 Phenanthroline Mono Hydrochloride	3600/5 gm
	Total Price	**Rs. 41895**

** According to Standard Methods for the examination of water and wastewater (APHA, 2005), for each COD sample, 3.5 ml of Sulphuric acid is required. Therefore, from 2500 ml bottle 700 samples can be prepared.

If frequency of analysis is thrice a week, these solutions need to be purchased after

$$= \frac{700}{(2(\text{samples})+1(\text{blank}))*3(\text{times a week})*4(\text{weeks})*12(\text{months})}$$

$$= 1.62 \text{ years}$$

** All other chemicals are sufficient for even 5 to 7 years.

Current Practice at I-9 STP
As compared to the Closed Reflux Titrimetric Method, each vial costs = Rs. 500 approx. With frequency of analysis of thrice a week, one need to run = 2 samples*3 times a week*4 weeks* 12 months*Rs. 500 = Rs.1,44,000/ year For 1.62 years = Rs. 2,33,280

3.1.5 Analysis of Plant's Performance at different SRTs

The sludge retention time (SRT) is one of the important parameter for the operation of WWTPs, relating to growth rate of microorganisms and to effluent concentrations (Clara et al., 2004). Prior to this study, the plant was being operated at inconsistent SRT, due to which MLSS and MLVSS also remained variable, which affected the treatment performance of the plant. In this study, most suitable SRT for plant's operation based on optimum sludge characteristics and treatment performance was determined.

Sludge Retention Time (SRT) was calculated as given in Metcalf and Eddy, 2003.

$$SRT = \frac{VX}{Q_W X_R + Q_e X_e} \qquad \text{-------------------------Eq (3.1)}$$

Where V= volume of the reactor, m^3

X= aeration tank mass concentration, mg/L

Q_w= waste sludge flowrate from the return sludge line, m^3/d

X_R= concentration of sludge in the return sludge line, mg/L

Qe= effluent flowrate from secondary clarifier, m^3/d

Xe= effluent TSS concentration, mg/L

Neglecting concentration of solids in the effluent, equation reduces to

$$SRT = \frac{VX}{Q_W X_R} \quad \text{-----------------------------------Eq (3.2)}$$

Since the Biological Oxygen Demand (BOD) of the influent was quite low, a large SRT of 12 days was adopted initially followed by SRT of 8 days and finally 7 days.

Table 3.5: Different SRTs adopted and calculations of $Q_{wastage}$

Sludge Retention Time	**Calculations**	**Comments**
For 12 Days SRT	$SRT = \frac{VX}{Q_{wastage} X_R}$ $Q_{wastage} = \frac{3600x3}{12x8}$ $Q_{wastage} = 112\ m^3/day$	SAS Pump was operated for 3 hrs a day based upon the pumping capacity of 40 m^3/hr.
For 8 Days SRT	$SRT = \frac{VX}{Q_{wastage} X_R}$ $Q_{wastage} = \frac{3600x3}{8\ x78}$ $Q_{wastage} = 169\ m^3/day$	SAS Pump was operated for 4 hrs a day based upon the pumping capacity of 40 m^3/hr.
For 7 Days SRT	$SRT = \frac{VX}{Q_{wastage} X_R}$ $Q_{wastage} = \frac{3600x3}{7\ x\ 8}$ $Q_{wastage} = 193\ m^3/day$	SAS Pump was operated for 5 hrs a day based upon the pumping capacity of 40 m^3/hr.

3.2 MODELLING PHASE

In this phase, Aquifas+ software was used to calibrate I-9 Wastewater Treatment Plant. The graphical interface of the software is shown in figure below:

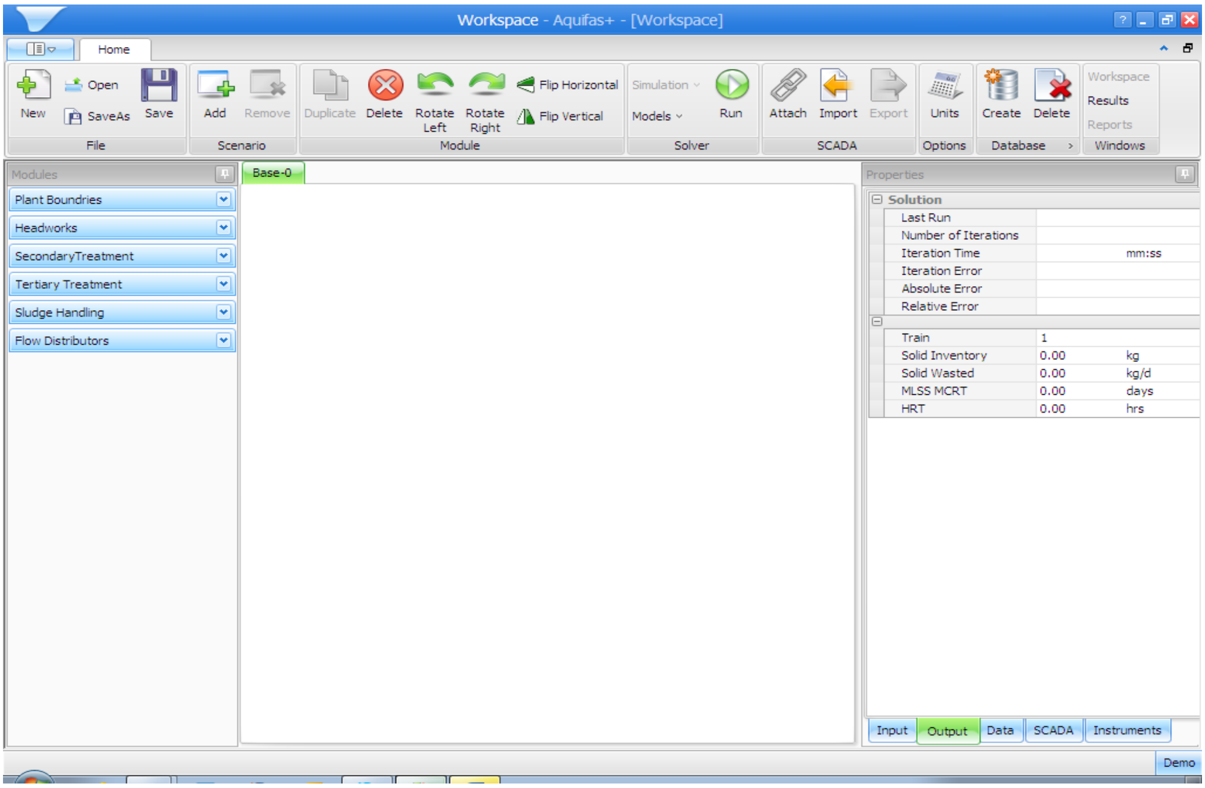

Figure 3.2: Graphical Interface of the software

In most applications, plant operation, influent and sludge characteristics require some of the model parameters to be adjusted. This process is generally referred to as model calibration (Brun et al., 2002).The stepwise procedure of modelling a WWTP in Aquifas+ is given below.

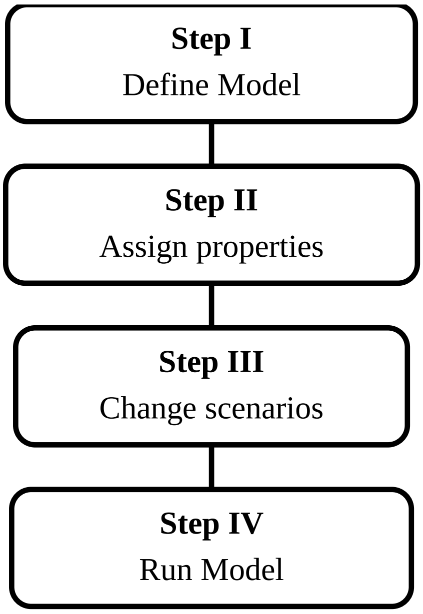

Figure 3.3: Steps involved in modelling WWTP in Aquifas+ software

The details of processes used in this software are as below.

3.2.1 Step I: Define Model in Aquifas+

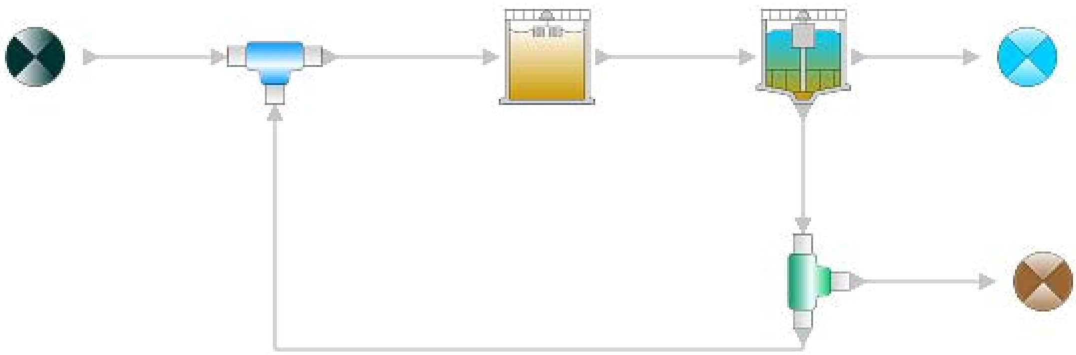

Figure 3.4: Model for Activated Sludge Process in Aquifas+

3.2.2 Step II: Assign properties to the model in Aquifas+

In this step, properties were assigned to each model component.

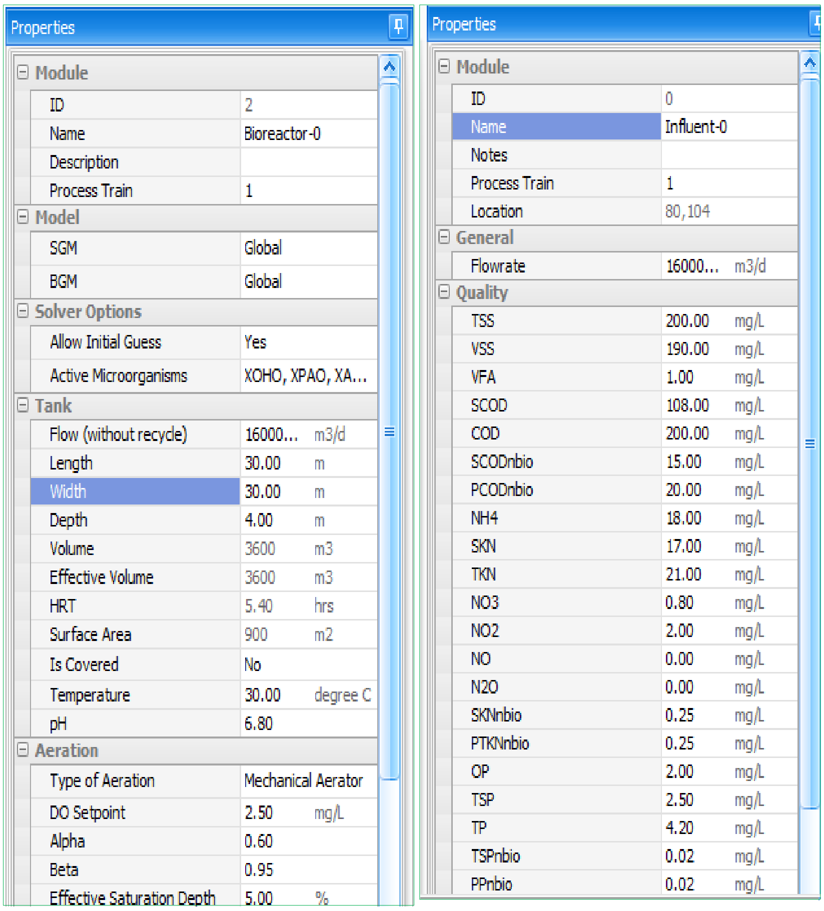

Figure 3.5: Properties assigned to different modules

3.2.3 Step III: Changing scenarios in Aquifas+

Aquifas+ software allows changing scenarios while remaining in the same file. In this step, three different scenarios were used to represent operating conditions at three different SRTs.

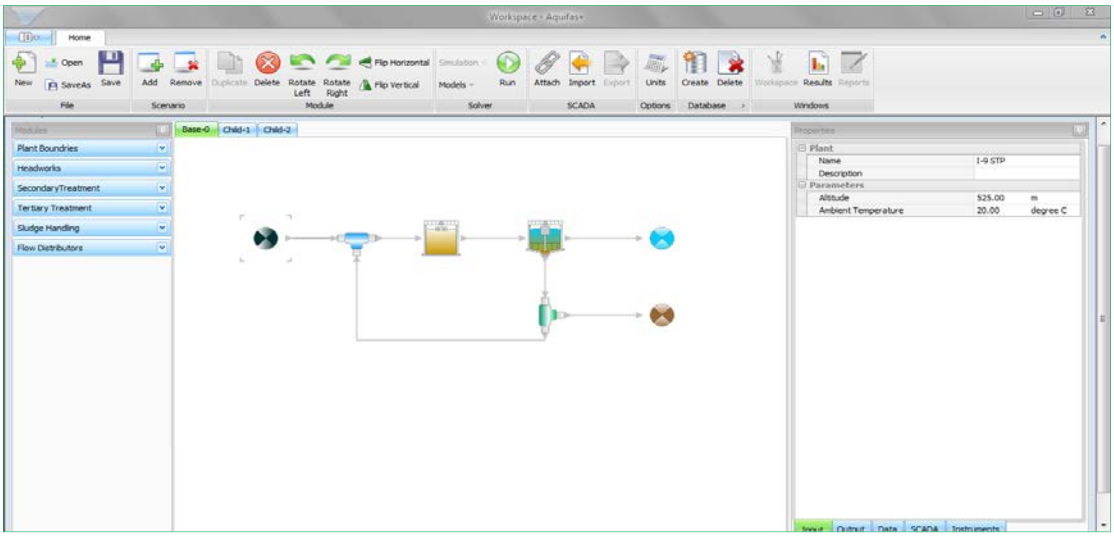

Figure 3.6: Different scenarios shown in Aquifas+

3.2.4 Step IV: Run model

In the final step, the Aquifas+ model was run to get the results.

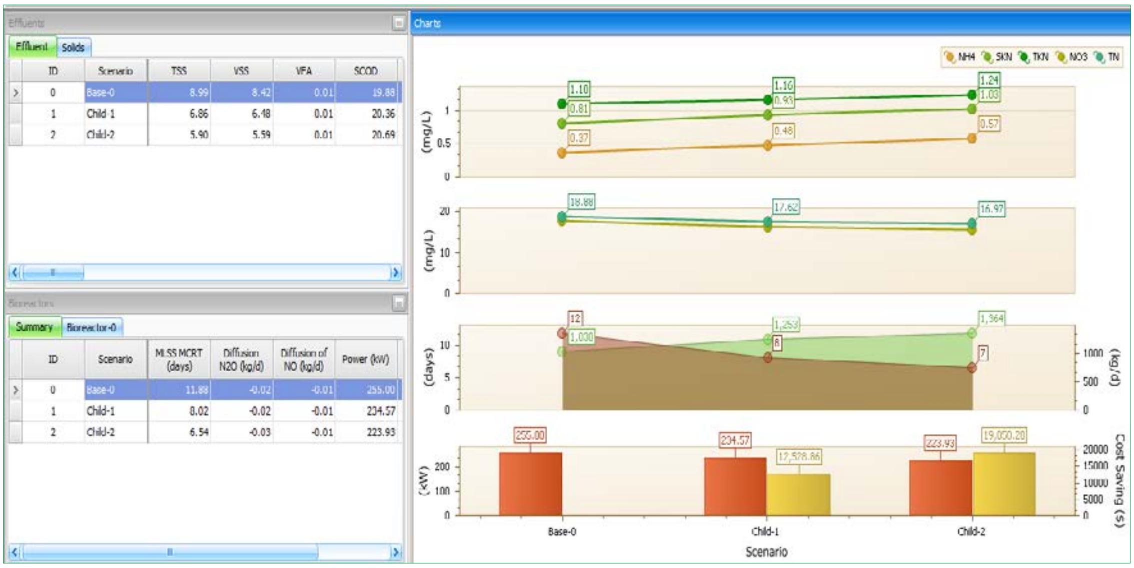

Figure 3.7: Effluent parameters obtained

Chapter # 4

RESULTS AND DISCUSSION

In this study the performance of the full scale sewage treatment plant located at sector I-9, Islamabad was analyzed in the first phase. In the second phase the collected data was used to model the STP performance using software Aquifas+.In the first part of this study a detailed wastewater characterization required by the process model was performed for incoming wastewaters to I-9 Wastewater Treatment Plant (WWTP), Islamabad and results obtained were used as inputs to the model. In the second part, existing plant was mathematically modelled by running Aquifas+ simulation software and measured concentrations of various parameters were compared with the model predictions.

4.1 ANALYSIS PHASE

This study was conducted over a period of 6 months (from Sept 2010 till Feb 2011) out of which regularly monitored data is being reported for 3 months period.

4.1.1 Wastewater Characterization

The composition of wastewater coming to I-9 STP, Islamabad and the typical domestic wastewater composition as per National Environmental Quality Standards (NEQS), Pakistan is listed in the table below.

Table 4.1: Influent wastewater characteristics at I-9 STP

S No.	Parameters	Influent Concentration Range at I-9 STP	Typical Influent Concentration as per NEQs
1	pH	7-8	6-9
2	Temperature	16-30^{o}C	≥3^{o}C
3	TSS	200-300 mg/L	400 mg/L
4	BOD	75-180 mg/L	250 mg/L
5	COD	250-350	400 mg/L

Table 4.1 shows that the pH of wastewater coming into the I-9 STP is above 7 because of the occurrence of surfactants normally present in domestic wastewaters. However, it is still in the

reference range of National Environmental Quality Standards (NEQS) Pakistan. Continuous analysis of the plant revealed that the BOD of the influent was low suggesting dilution with the storm water from leaking pipes. The BOD/COD ratio of the plant was also quite low i.e., below 0.5.

4.1.2 I-9 STP Description

This treatment plant is located at sector I-9, Islamabad. It has four phases out of which Phase 1 was constructed in 1964. In 2005 the three existing plants (Phases 1, 2 & 3) were refurbished and a new plant (Phase 4) was designed.

Figure 4.1: Satellite image of I-9 STP, Islamabad, obtained from Google Earth

The Phase 4 Sewage Treatment Plant was built and commissioned in 2007 for a treatment capacity of 20, 000 PE with an average daily flow of 10 MGD and Peak Wet Weather flow of 20 MGD/24h. The catchments area served by the Phase 4 plant is from sectors 10 & 11 of D, E, F, G &H series.

Table 4.2: Average daily flow at different phases of I-9 STP

Plant	Capacity	Average Daily Flow	Peak Wet Weather Flow
Phase 1 & 2	80, 000 PE	4 MGD	8 MGD/24h
Phase 3	55,000 PE	3 MGD	6 MGD/24 h
Phase 4	200,000 PE	10 MGD	24 MGD/24 h

In this study, the performance of Phase 4 of I-9 STP having a capacity of 10 MGD was evaluated and optimized.

4.1.3 I-9 STP Process Design

The treatment process consists of

- Pretreatment including fine bar screening and grease-grit removal
- Primary Settlement Tanks
- Activated Sludge Process Using Surface Aeration
- Secondary Settlement Tanks
- Sludge treatment processes

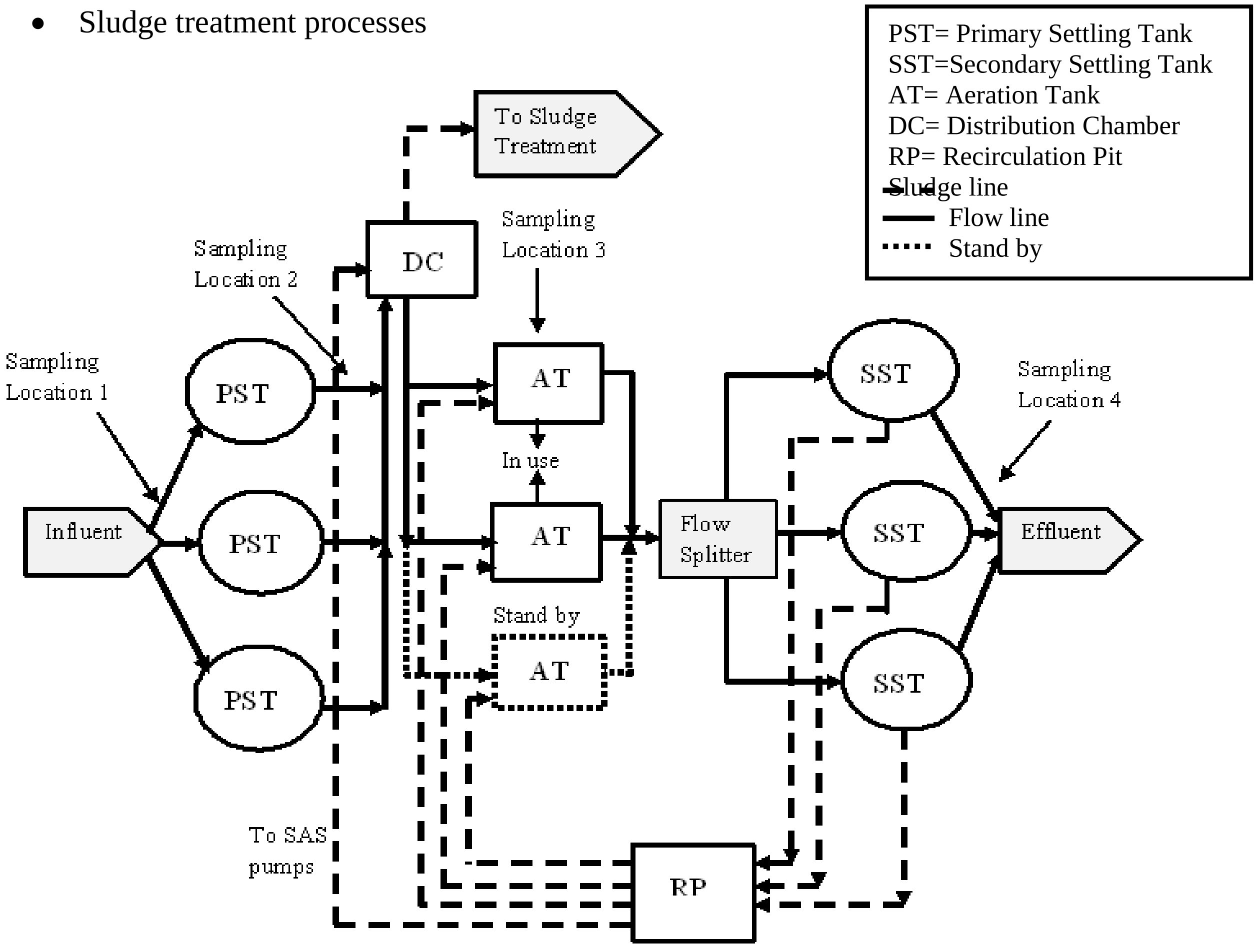

Figure 4.2: Layout of I-9 STP showing Sampling Locations

4.1.4 I-9 STP Operational Parameters

4.1.4.1 Temperature

The temperature of wastewater varied between 14-30^oC during the study as shown in Figure 1. The temperature profile shows the drop in wastewater temperature from 30^oC at the start of December 2010 to 15^oC by mid January 2011 and remained in the range of 14-16^oC till end of February 2011.

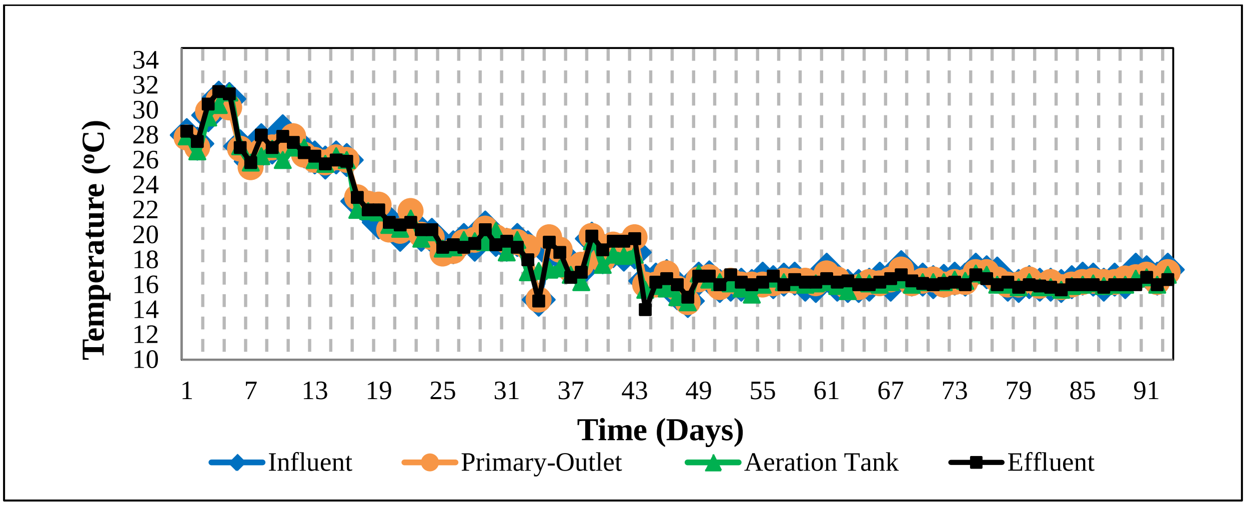

Figure 4.3: Temperature variations observed during the study

4.1.4.2 Flow rate

The influent flow rate coming to the plant varied from 3.94 MGD to 5 MGD at Phase IV of I-9 STP. The profile of influent wastewater flow-rate to the plant is shown in Figure 4.4.

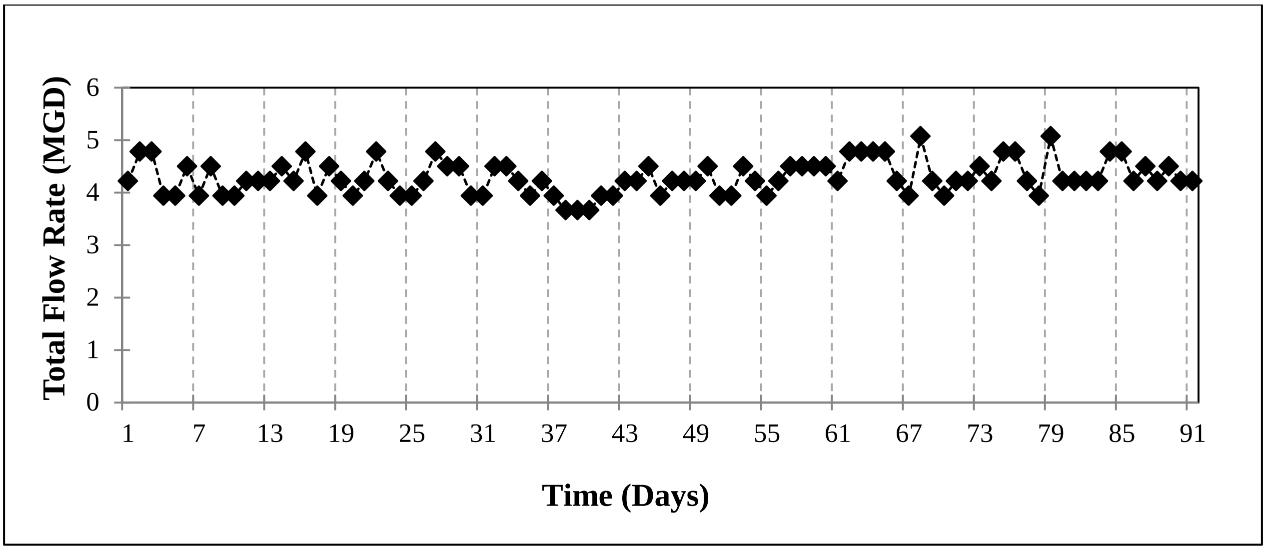

Figure 4.4: Influent Flow rate profile at phase IV of I-9 STP

4.1.4.3 Solids Retention Time (SRT)

The solids retention time (SRT) is one of the important parameter for the operation of WWTPs relating to growth rate of microorganisms and to effluent concentrations (Clara et al., 2004). Prior to this study, the plant was being operated at inconsistent SRT, due to which MLSS and MLVSS also remained variable, which affected the treatment performance of the plant. In this study, most suitable SRT for STP operation was determined based on optimum sludge characteristics and treatment performance.

Since the Biological Oxygen Demand (BOD) of the influent was quite low, a large SRT of 12 days was adopted initially followed by SRT of 8 days and finally 7 days.

4.1.5 Influence of SRT on Treatment Performance & Sludge Characteristics

The performance and the conditions at the STP plant are discussed in detail below:

4.1.5.1 Total Suspended Solids (TSS)

The TSS concentrations over time are shown in Figure 5. It was observed that the TSS did not vary considerably and the removal efficiency was 90-92%. Also, the effluent TSS concentration was with in limits of the national environmental quality standards (NEQs) as well as European standards of water quality. The decrease in MLSS from 3680 mg/L at 12 day SRT to 3410 mg/L at 7 day SRT did not have negative impact on the sludge blanket depth in the clarifier and subsequent TSS concentration in the effluent.

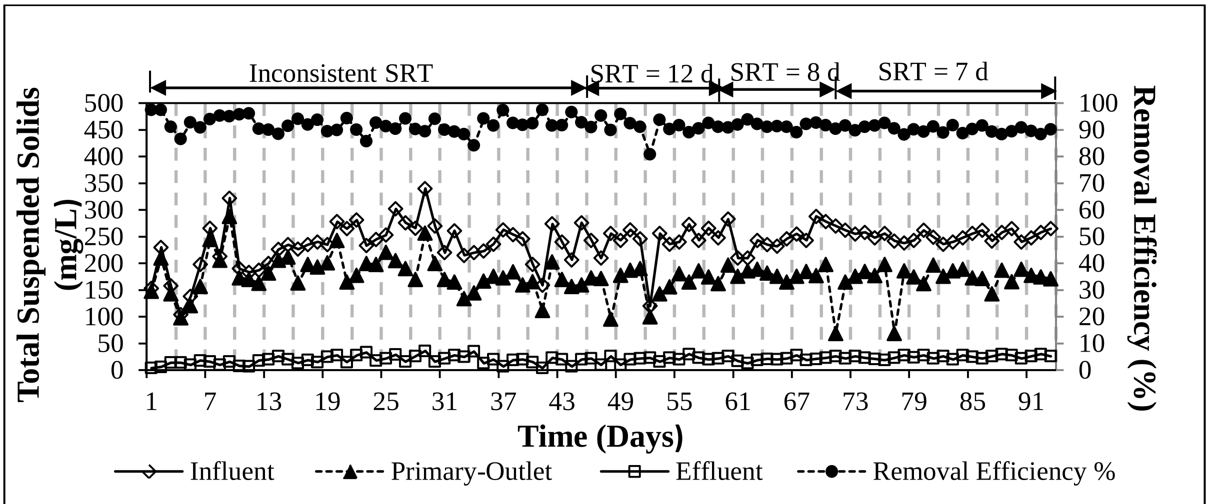

Figure 4.5: TSS concentration and removal efficiency at different SRTs

4.1.5.2 Biological Oxygen Demand (BOD)

The variability of BOD with respect to time is shown in Figure 4.6. Operation at inconsistent SRT in the beginning resulted in poor BOD removal efficiency as presented in Table 3. At 12 days SRT, there was an increase in BOD removal efficiency. Consistency in BOD removal efficiency was achieved at an optimized SRT of 7 days.

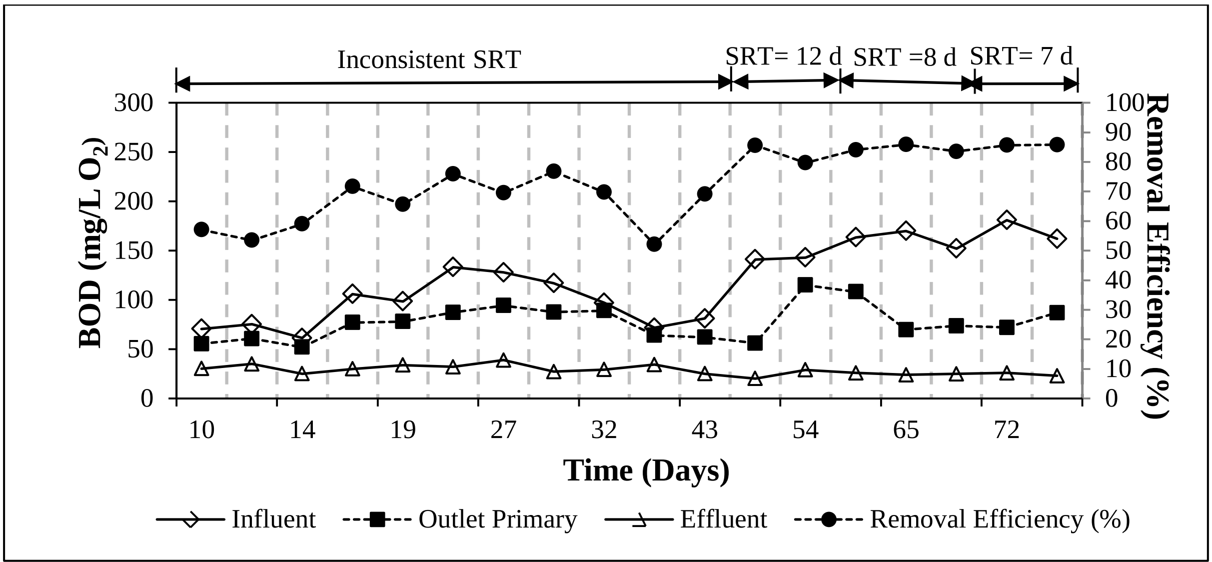

Figure 4.6: BOD concentration and removal efficiency at different SRTs

4.1.5.3 Chemical Oxygen Demand (COD)

The COD profile observed during the study is shown in Figure 4.7. Initially at inconsistent SRT, the COD removal efficiency was low. At 12 days SRT, the COD removal efficiency was increased which became consistent at optimized SRTs of 8 and 7 days.

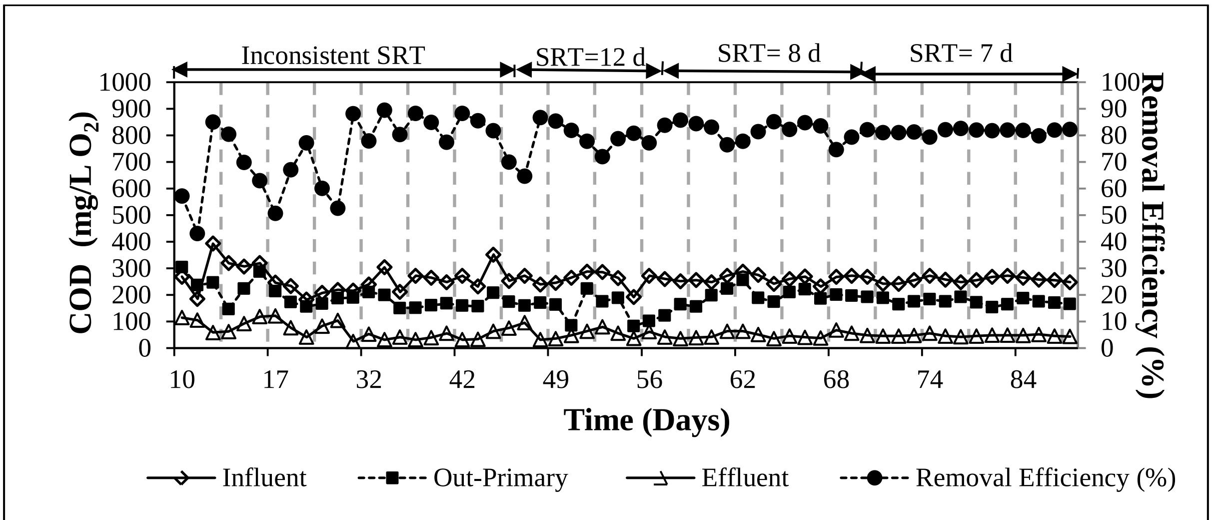

Figure 4.7: COD concentration and removal efficiency at different SRTs

4.1.5.4 Biomass Concentration (MLSS & MLVSS)

MLSS and MLVSS concentration was determined regularly, at variable SRTs. Prior to the study, the plant was being operated at inconsistent SRT due to which MLSS/MLVSS levels kept fluctuating as shown in Figure 4.8. The average ratio of MLVSS/MLSS of the sludge in the aeration tank was found to be 77-79% at variable SRTs.

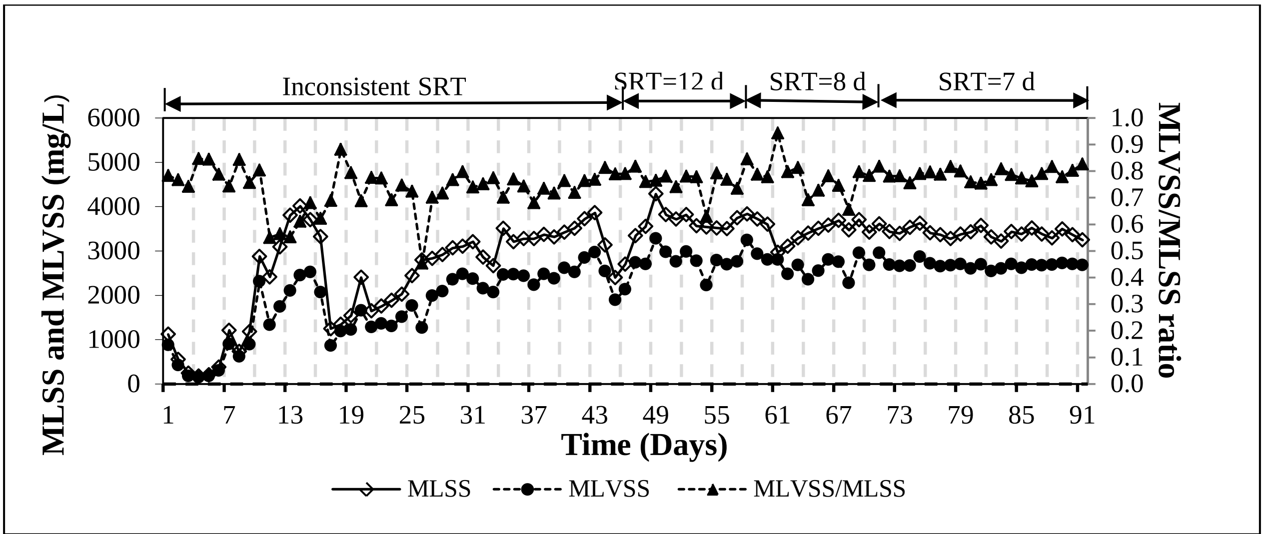

Figure 4.8: MLSS and MLVSS concentration and MLVSS/ MLSS ratio

4.1.5.5 Hydraulic Retention Time (HRT)

Due to inadequate infrastructure of pipelines in the city, phase IV of I-9 STP is receiving only 4-5 MGD of sewage per day. Since the plant is receiving the sewage only half of its capacity, only two aeration tanks are functional. In the above formula volume of two aeration tanks is used instead of three. The HRT profile of the plant is presented in Figure 4.9. The HRT of the plant varied from 4.57 to 6.33 hr with a standard deviation of ±0.4 hr. The average HRT of the aeration tank was found to be 5.48 hrs. Calculations of HRT are given in Appendix A.

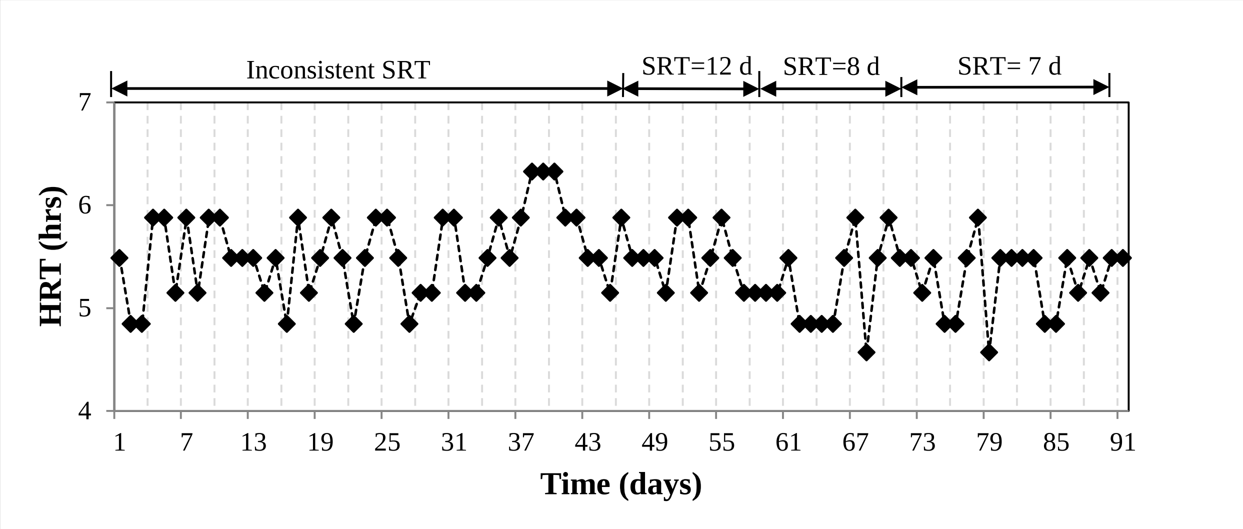

Figure 4.9: Hydraulic retention time of the aeration tank at variable SRTs

4.1.5.6 Volumetric Organic Loading Rate (OLR)

The volumetric organic loading rate (OLR) is defined as the amount of BOD or COD applied to the aeration tank volume per day. Organic loadings expressed in kg BOD or COD/m^3.d, may vary from 0.3 to more than 3 (MetCalf and Eddy, 2003). In this study, the organic loading rate profile is shown in the figure below.

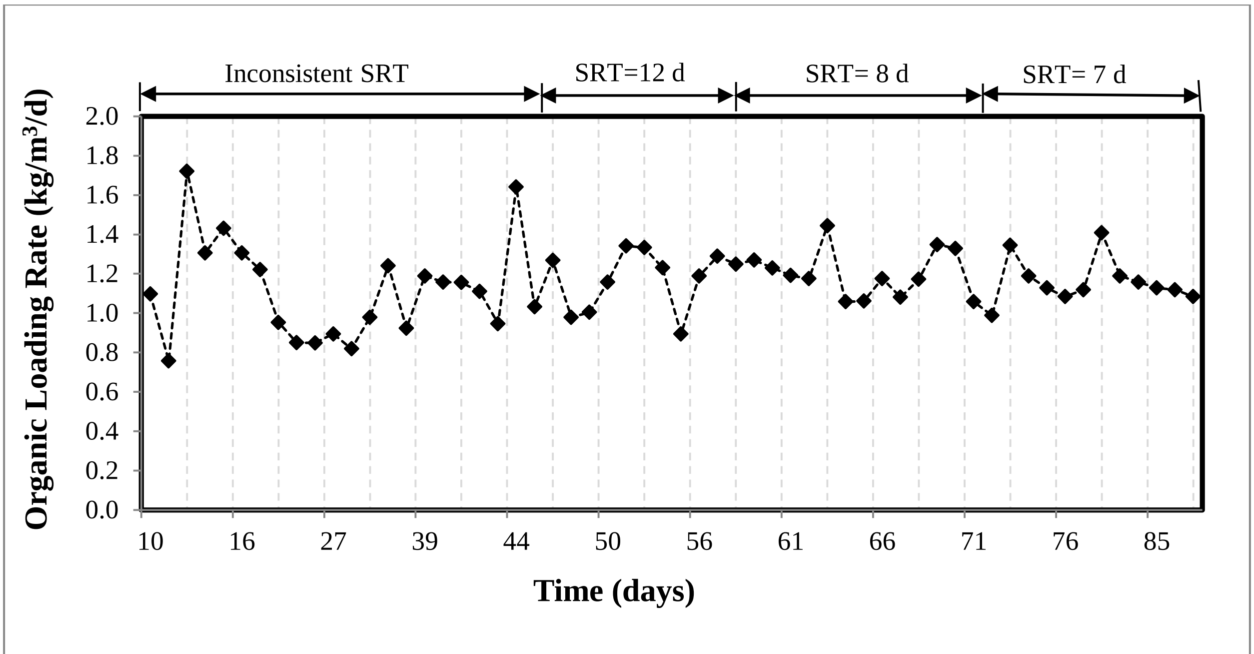

Figure 4.10: Organic loading rate in the aeration tank at variable SRTs

4.1.5.7 Food to Microorganisms (F/M ratio)

The food to microorganism ratio has a specific influence on sludge characteristics and floc size distribution (Barbusinski and Koscielniak, 1995). Due to inconsistent sludge wastage by SAS pump, the food to microorganisms (F/M) ratio changes which affects the microbial activity. Therefore, it is necessary that proper f/m ratio is maintained in the aeration tank in order to have an optimum operation by the activated sludge bacteria.

In this study, at inconsistent SRT the F/M ratio was high with an average value of 0.29±0.11. On increasing the SRT to 12 days, the average value of F/M ratio was found to be 0.1±0.02. Since F/M ratio is inversely related to SRT, at decreased sludge age of 8 days the F/M ratio increased to 0.2±0.03. At 7 days SRT, the average F/M ratio was also 0.2±0.01. Calculations for F/M ratio are given in Appendix A.

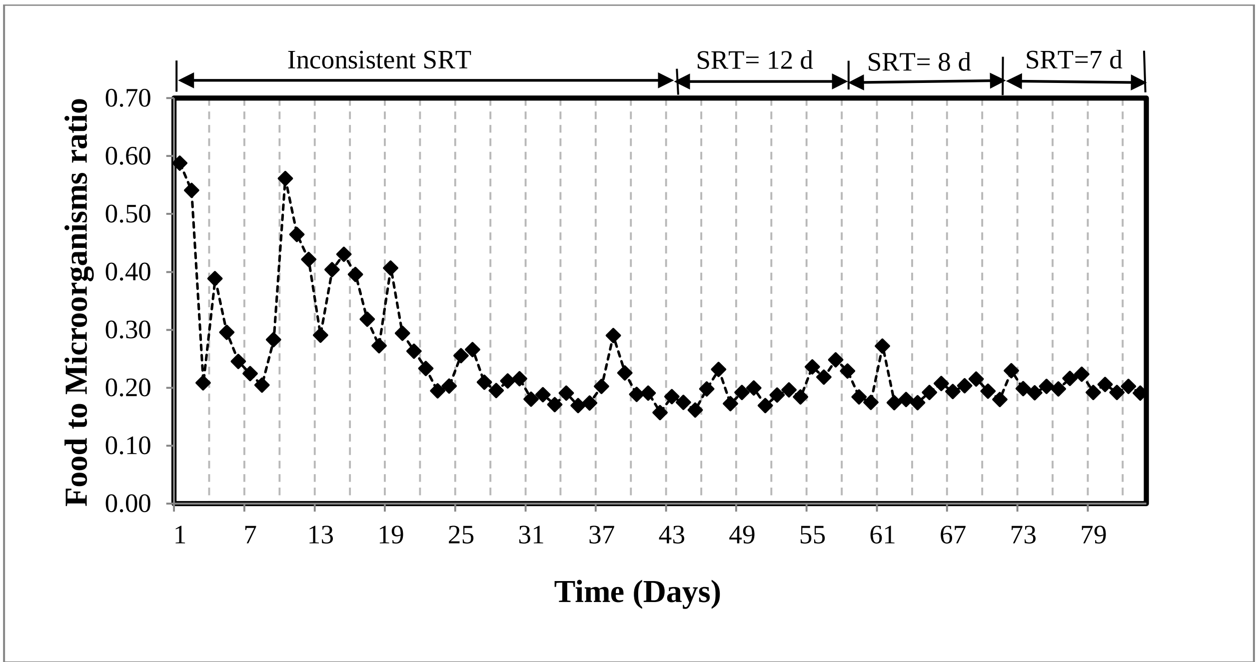

Figure 4.11: Food to microorganisms (F/M) ratio in the aeration tank at variable SRTs

4.1.5.8 Specific Oxygen Uptake Rate (SOUR)

The specific oxygen uptake rate is a measure of biological activity of microorganisms. At 12 day SRT, there was occurrence of odor and scum layer in the secondary clarifier. Table 3 shows that at inconsistent SRT, SOUR value was quite low indicating low activity of microorganisms but with improved SRT of 7 days the biological activity of the microorganisms improved.

4.1.5.9 Sludge Volume Index (SVI)

The sludge volume index is used to measure the settling characteristics of sludge. In this study, the SVI value was observed to be high at inconsistent SRT. At 12 days SRT, the SVI value further increased indicating rise in the sludge blanket depth in the final clarifier, resulting in scum layer formation as well as odor problem. To counter with the scum and odor problem, sludge wastage rate was increased. At a decreased SRT of 8 days, the SVI value was also decreased indicating improvement in sludge settling characteristics. The odor problem was reduced considerably as well as scum layer started to disappear. Therefore it was suggested that the SRT should be further reduced to 7 days. After optimizing SRT, significant improvement was seen in sludge settling and scum layer formation.

Table 4.3: Treatment performance at different SRTs

Parameter	**Influent**	**Effluent Inconsistent SRT**	**Effluent 12 Days SRT**	**Effluent 8 Days SRT**	**Effluent 7 Days SRT**
Concentration (Removal efficiency)	**mg/L**	**mg/L (%)**	**mg/L (%)**	**mg/L (%)**	**mg/L (%)**
Biological Oxygen Demand (BOD)	120	31 (65)	27 (82)	25 (85)	24 (86)
Chemical Oxygen Demand (COD)	260	59 (73)	49 (81)	49 (81)	48 (82)
Total Suspended Solids (TSS)	240	18 (92)	20 (91)	22 (91)	25 (90)

Table 4.4: Sludge Characteristics at different SRTs

Parameter	Inconsistent SRT	12 Days SRT	8 Days SRT	7 Days SRT
Mixed Liquor Suspended Solids (MLSS)	2422	3680	3466	3410
Mixed Liquor Volatile Suspended Solids (MLVSS)	1736	2824	2692	2674
Food to microorganisms (F/M) ratio		0.29±0.11	0.19±0.02	0.20±0.03
Specific Oxygen Uptake Rate (SOUR) (mg/hr/gm)	25.7± 6.9	40.6± 13.3	51.9±4.2	55.4 ±2.0
Sludge Volume Index (SVI) (mL/gm)	178 ± 25	188 ± 15	178 ± 22	139 ± 9

Table 4.3 and 4.4 represents the treatment plant performance indicators and sludge characteristics, respectively at inconsistent SRT [inconsistent sludge wasting by surplus activated sludge (SAS) pumps] followed by consistent 12 days, 8 days and finally 7 days SRT.

4.2 MODELLING PHASE

The benefits of process modelling and simulation are obvious in terms of the many purposes that it can serve. For the process engineer it is possible to explore different process configurations or operating strategies for an existing plant. For the operator, the plant behavior can be predicted under various operations and different what–if situations can be explored (Olsson and Newell, 1999). Considering the past operational problems at I-9 STP, Islamabad, construction of a credible mathematical model of the plant has become an unavoidable task. In this part of the study, plant model was calibrated for the removal of carbonaceous components.

In order to simulate the processes at I-9 STP, Islamabad, Aquifas+ was used. This software has been developed by IESE student Mr. Adnan Lodhi and was available free of cost. It is the extension and enhancement of IWA-ASM2d model. It is a Microsoft. NET based application which uses sophisticated numerical analytic technique to solve the system of non-linear model mass balance equations (Sen and Lodhi, 2010). The software has GUI environment which allow the user to drag and drop models of different process units.

4.2.1 Model and the Simulation Environment

Plant layout including influent module, a flow combiner, a flow splitter, a aeration tank and final settling tank was easily transferred on the Aquifas+ screen as first step using user friendly graphical icons. In order to keep the model simple, we omitted the primary clarifier since our main aim was to simulate the processes in the aeration tank. After constructing the layout of the plant, some necessary data on physical specifications of the units, and type of the aerators entered into the software as given in Table 4.5. Some operational parameters of the treatment plant which were entered to the Aquifas+ software as operational data are given in Table 4.6. Daily average values of influent wastewater constituents and influent wastewater flow-rate were used as input to the model.

Table 4.5: Characteristics of Aeration tank and Final Clarifier

Aeration Tank Dimensions		**Secondary Clarifier Dimensions**	
No. of tanks	3	No. of Clarifiers	3
Tank Dimensions (LxWxH)	(30x15x4) m	Water height	3 m
Total Length	30 m	Diameter	37 m
Total Width	30 m	Equivalent diameter	64 m
Total Area	900 m^2	Total Area	3225 m^2
Total Volume	3600 m^3	Total Volume	9675 m^3
Aeration Equipment	Mechanical aerators		
DO set point	2.5 mg/L		

Table 4.6:Operational parameters of the treatment plant at different SRTs

Sludge age			
	12 days	**8 days**	**7 days**
Daily Mean Flow rate	15973 m^3/d	15973 m^3/d	15973 m^3/d
Waste sludge Flowrate	120 m^3/d	160 m^3/d	200 m^3/d
Sludge Concentration in the return sludge line	8 g/L	8 g/L	8 g/L

4.2.2 Model Calibration

Model calibration is an important step in any modelling effort. In calibration, values are assigned to the parameters used in the model such that the difference between model predictions and observations is at its minimum.

4.2.3 Evaluation of Simulated results

Measured and simulated BOD values are shown in Figure 4.12. The measured values are on a higher side than those of simulated with the software. But the difference between the values is very low. However, the trend of both the simulated and measured values is not similar which needs further investigation.

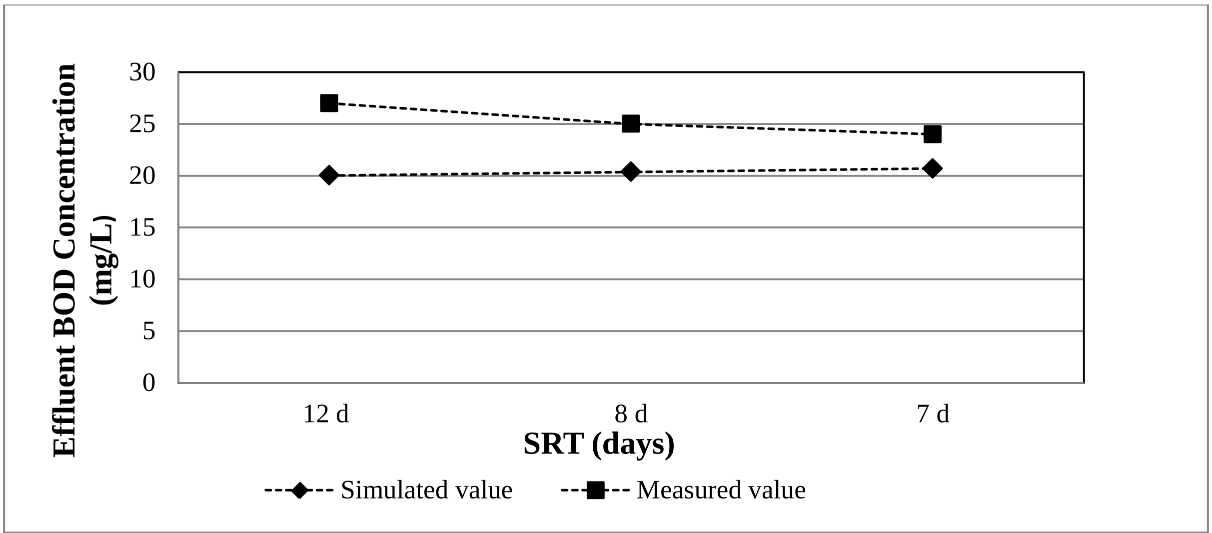

Figure 4.12: Comparison of simulated and measured BOD values

Figure 4.13 shows comparison of simulated and measured COD values. One can see that the difference between simulated and measured COD is much than BOD values. The reason behind is that the COD is more complex than BOD as COD comprises of biodegradable and non biodegradable fractions which can be further divided into readily biodegradable and slowly biodegradable as well as soluble and particulate COD. In this study, we have only measured the soluble and biodegradable chemical oxygen demand, while other parameters have not been measured. But the trend observed is similar in both the simulated and measured values as shown in Figure 4.13.

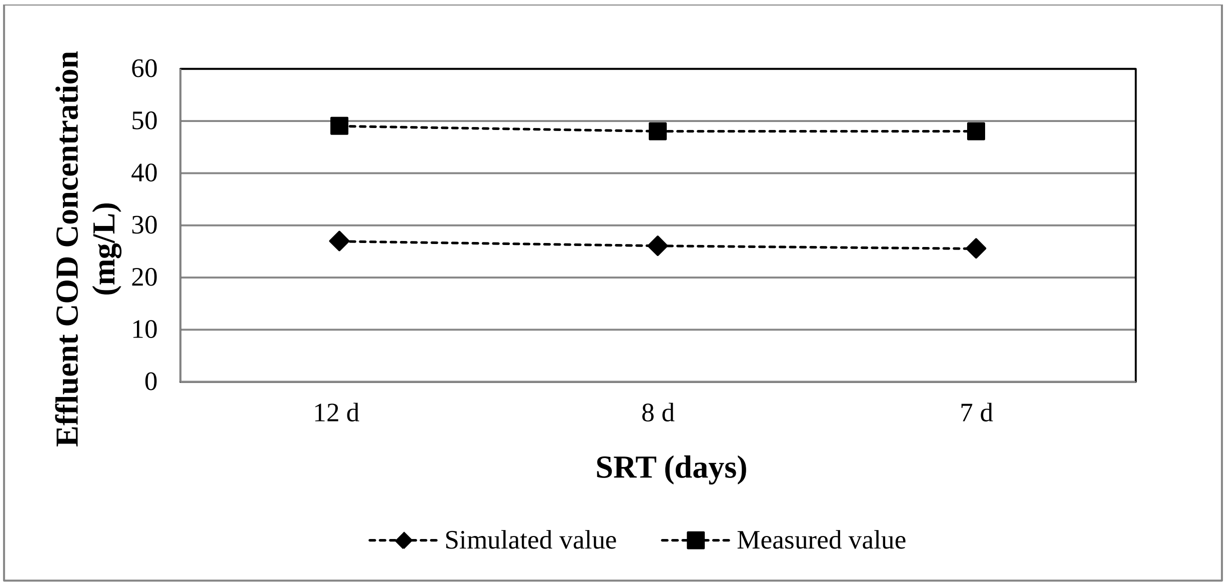

Figure 4.13: Comparison of simulated and measured COD values

Figure 4.14 shows the comparison of values between simulated and measured MLSS concentration. Again the trend is similar in the simulated and measured values.

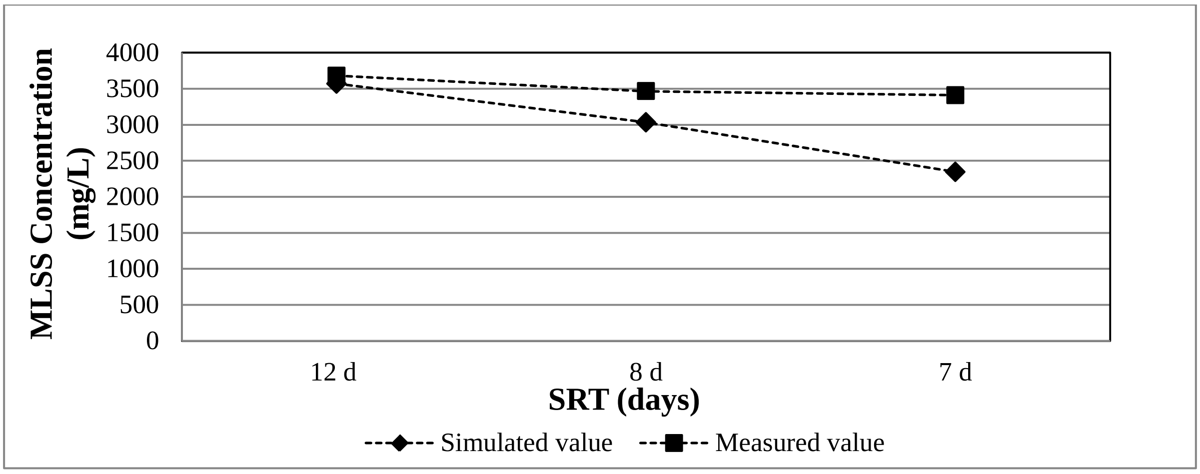

Figure 4.14: Comparison of simulated and measured MLSS concentration

CONCLUSIONS AND RECOMMENDATIONS

This study investigated the treatment performance of full scale wastewater treatment plant using activated sludge process at Islamabad, Pakistan. Moreover, the operating conditions at the plant were determined and regularly monitored. It was found that the treatment performance of the plant was below desired levels due to low MLSS/MLVSS conditions as a result of inconsistent sludge wastage by the SAS pumps. This study revealed that the desired MLSS concentration in the range of 3000-3500 mg/L could be maintained by optimizing the SRT. It was found that SRT of 7 days was the optimum value resulting in the desired MLSS range, avoiding odor and scum formation as well as achieving maximum removal efficiencies of TSS, BOD and COD. The conclusions drawn from the study are presented as below:

5.1 CONCLUSIONS:

- It was found that phase IV of I-9 STP was receiving almost 50% of its design flow capacity(4-5 MGD instead of 10 MGD capacity).
- Treatment performance of the plant was improved at SRTs of 12 d, 8 d &7 d while maximum removal efficiencies of BOD (86%), COD (82%) and TSS (90%) were achieved at 7 d SRT
- Maximum removal efficiencies were associated with stability of MLSS (3000-3500mg/L)& F/M ratio (0.2/day)
- The measured data of I-9 Sewage Treatment Plant (STP) was calibrated by using simulation software Aquifas+ and a steady state model was obtained.

5.2 RECOMMENDATIONS:

Treatment performance evaluation of a full scale STP was performed during this study. Following are the recommendations for future study:

- Seasonal variations in the treatment performance of the plant should be observed.
- The calibrated model should be further fine tuned by incorporating other parameters required in the software.
- Dynamic modelling should be explored

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Appendix-A

CALCULATIONS FOR DIFFERENT PARAMETERS

Appendix A

Calculations for HRT

Total volume of 3 Aeration Tanks = 3* (30*15*4) m^3

Hydraulic Retention Time = $\frac{\text{Volume of the Aeration Tank}}{\text{Average Flow rate}}$

Since average flow rate is 4.22 MGD

1 MGD = 4.3183 x 10^{-2} m^3/s

4.22 MGD = 656 m^3/hr

Since two aeration tanks are operating at present, we will use the aeration tank volume of two tanks in calculations.

$$\text{HRT} = \frac{(30*15*4)\ m^3 \times 2}{656\ m^3/hr}$$

= 5.48hrs

Calculations for F/M ratio

$$\text{F/M ratio} = \frac{\text{Flow (MGD) x Influent CBOD(mg/L)}}{\text{MLVSS (mg/L) x Volume of Aeration Tank (MG)}}$$

$$= \frac{4.22 \times 116}{2600 \times 0.95}$$

= 0.20/day

Appendix-B

PROTOCOLS FOR DIFFERENT PARAMETERS

Appendix-B

1. MLSS (Mixed Liquor Suspended Solids)/ MLVSS (Mixed Liquor Volatile Suspended Solids) Measurements

Procedure

Preparation of filter paper

- Warm-up muffle furnace and adjust the temperature to 550^0C.
- Heat GFC filter paper in a clean evaporating dish in the oven for 15 minutes at 550^0C.
- Place the dish in a desiccator to cool.
- Weigh the dish on balance and note the weight.

Determination of MLSS

- Assemble filtering apparatus and filter and begin suction.
- Wet filter with a small volume of reagent-grade water to seat it
- Pipette a measured volume onto the seated glass-fiber filter.
- Wash filter with three successive 10 mL volumes of reagent-grade water, allowing complete drainage between washings, and continue suction for about 3 min after filtration is complete.
- Carefully remove filter from filtration apparatus and transfer to china dish and put it in oven and dry for at least 1 h at 103 to 105°C in an oven, cool in a desiccator to balance temperature, and weigh.
- Repeat the cycle of drying, cooling, desiccating, and weighing until a constant weight is obtained or until the weight change is less than 4% of the previous weight or 0.5 mg, whichever is less.

Calculation

$$MLSS\frac{mg}{L} = \frac{(A - B) \times 1000}{SampleVolume, mL}$$

where:

A = weight of filter + dried residue, mg, and

B = weight of filter, mg.

Determination of MLVSS

- Place the above GFC filter in a muffle furnace already set at 550°C for 15 minutes.
- Cool in a desiccator and weigh.

$$MLVSS\ \frac{mg}{L} = \frac{(A - B) \times 1000}{Sample\ Volume, mL}$$

where:

A = weight of residue + filter before ignition, mg,

B = weight of residue + filter after ignition, mg, and

2. Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. The quantity of oxidant consumed is expressed in terms of its oxygen equivalence.

Method

Closed Reflux, Titrimetric Method

Chemicals Required

1. Potassium dichromate ($K_2Cr_2O_7$) 0.01667M
2. Sulphuric acid (H_2SO_4)
3. Mercuric sulphate ($HgSO_4$) crystals
4. Ferrous ammonium sulphate (FAS) [$Fe(NH_4)_2(SO_4)_2$], approximately 0.01N
5. Ferroin indicator (1, 10-phenanthroline and ferrous ammonium sulphate)

Reagents Preparation

a. ***Standard potassium dichromate digestion solution,* 0.01667*M***

Add to about 500 mL distilled water 4.903 g $K_2Cr_2O_7$, primary standard grade, previously dried at 150°C for 2 h, 167 mL conc H_2SO_4, and 33.3 g $HgSO_4$. Dissolve, cool to room temperature, and dilute to 1000 mL.

b. ***Sulfuric acid reagent***

Add Ag_2SO_4, reagent or technical grade, crystals or powder, to conc H_2SO_4 at the rate of 5.5 g Ag_2SO_4/kg H_2SO_4. Let stand 1 to 2 d to dissolve.

c. Ferroin indicator solution

Dissolve 1.485 g 1,10-phenanthroline monohydrate and 695 mg $FeSO_4.7H_2O$ in distilled water and dilute to 100 mL. This indicator solution may be purchased already prepared. Dilute this reagent by a factor of 5 (1 +4).

d. Standard ferrous ammonium sulfate titrant (FAS)*, approximately 0.10*N

Dissolve 39.2 g Fe $(NH_4)_2(SO_4)_2.6H_2O$ in distilled water. Add 20 mL conc H_2SO_4, cool, and dilute to 1000 mL.

Standardize solution daily against standard $K_2Cr_2O_7$ digestion solution as follows:

- Pipet 3 mL digestion solution into a small beaker.
- Add 5 mL reagent water to substitute for sample and 7mL H2SO4.
- Cool to room temperature.
- Add 1 to 2 drops diluted ferroin indicator and titrate with FAS titrant.

Normality of FAS solution

$$N\ of\ FAS = \frac{Volume\ 0.01667M\ K_2Cr_2O_7\ solution\ titrated, ml}{Volume\ of\ FAS\ used\ in\ titration, mL} \times 0.100$$

Table B-1: Sample and reagent quantities for various digestion vessels

Digestion Vessel	Sample *mL*	Digestion Solution *mL*	Sulfuric Acid Reagent *mL*	Total Final Volume *mL*
Culture tubes:				
16 × 100 mm	2.50	1.50	3.5	7.5
20 × 150 mm	5.00	3.00	7.0	15.0
25 × 150 mm	10.00	6.00	14.0	30.0
Standard 10-mL ampules	2.50	1.50	3.5	7.5

Procedure

- Wash culture tubes and caps with 20% H_2SO_4 before first use to prevent contamination.
- Ovens dry the tubes in pre-heated oven at 150oC for 1 hr.
- Take tubes out of oven and let them stay to cool.
- Refer to Table B-1, for proper sample and reagent volumes.
- Place sample in culture tube or ampule and add digestion solution.
- Carefully run sulfuric acid reagent down inside of vessel so an acid layer is formed under the sample-digestion solution layer.
- Tightly cap tubes or seal ampules, and invert each several times to mix completely.
- Place tubes or ampules in block digester (or oven) preheated to 150°C and reflux for 2 h behind a protective shield.
- Cool to room temperature and place vessels in test tube rack.
- Remove culture tube caps and transfer contents to a larger container (flask) for titration and add small TFE-covered magnetic stirring bar.
- Add 0.05 to 0.10 mL (1 to 2 drops) ferroin indicator and stir rapidly on magnetic stirrer while titrating with standardized 0.10N FAS.
- The end point is a sharp color change from blue-green to reddish brown, although the blue-green may reappear within minutes.
- In the same manner reflux and titrate a blank containing the reagents and a volume of distilled water equal to that of the sample.

Calculation

$$COD\ as\ mg\frac{O_2}{L} = \frac{(A - B) \times M \times 8000}{mL\ sample}$$

Where:

A = mL FAS used for blank,

B = mL FAS used for sample,

M = molarity of FAS, and

8000 = milliequivalent weight of oxygen × 1000 mL/L.

Caution

- Wear face shield and protect hands from heat produced when contents of vessels are mixed. Mix thoroughly before applying heat to prevent local heating of vessel bottom and possible explosive reaction.
- These sealed vessels may be under pressure from gases generated during digestion so wear face and hand protection when handling. If sulfuric acid is omitted or reduced in concentration, very high and dangerous pressures will be generated at 150°C.

3. Specific Oxygen-Consumption Rate (SOUR)

This test is used to determine the oxygen consumption rate of a sample of a biological suspension such as activated sludge.

Substrate Solution Preparation

Stock Solution

- **Glucose Solution**

The concentration of substrate sample was determined using the following equation

C = aXV/ v

Where

C = Substrate concentration in 1 mL injected sample

a = S/X ratio = 0.02 gCOD/gVSS (Mathieu and Etienne, 2000).

S = Substrate concentration (mgCOD/L)

X = Biomass concentration ~ 6000mg/L

V = Respirometer vessel = 300 mL (BOD bottle)

v = Volume of substrate injected = 1 mL

C = (0.02 * 6000 * 300)/1 = 36,000 mg/L

Final concentration in BOD bottle after injection = 120 mgCOD/L

- **Ammonium Solution**

C = 6,000 mg/L

Final concentration in BOD bottle after injection = 20 mg NH_4^+-N/L

Table B-2: Quantity of glucose & ammonium chloride required per 50 mL

Chemical	Quantity per 50 mL (mg)	Stock Solution Concentration (mg/L)	Final Concentration in 300 mL (mg/L)
Hydrated Glucose	1,856.3	36,000	120
Ammonium Chloride	1,146.5	6,000	20

Sample Preparation

Take 900 mL sludge in 1L beaker and aerate it for about 2 hrs to reach endogenous phase, so that DO > 6 mg/L and all substrate has been consumed.

Conditions for SOUR determination

a) Endogenous SOUR

Take 300 mL sludge sample in BOD bottle from above well aerated sample.

Determine SOUR (without any substrate addition).

b) Exogenous SOUR

Take 300 mL sludge sample in BOD bottle from above well aerated sample.

Determine SOUR after injecting 1 mL of glucose stock solution.

c) Nitrogenous SOUR

Take 300 mL sludge sample in BOD bottle from above well aerated sample.

Determine SOUR after injecting 1 mL of ammonium chloride stock solution.

Nitrogenous SOUR = SOUR with ammonium chloride - Endogenous SOUR

SOUR measurement by 5100 DO meter

Calibration:

1. Place the probe in to the BOD bottle containing about 1” water.
2. On the instrument
3. Allow the probe to polarize and the temperature to stabilize for at least 15min.
4. Press the [CALIBRATE] soft key.

5. Make sure that the display readings are stable, and then press the [AUTO CAL] soft key.
6. The message “DO calibration saved” will be displayed for seconds.
7. Press [MODE] to return to main mode

Protocol

1. On the Y5100 DO meter.
2. Press [Mode] to enter into application mode
3. Press [SOUR] soft key.
4. Press [SETUP] to change the SOUR parameters
5. Use the [UP], [DOWN], [DIGIT] and [NEXT] soft keys to set the parameters as necessary

Parameters

- Sample/Total = 1/[Enter the ratio of the sample volume to total volume]
- Min time (min) = [minimum time to run the setup]
- Max. Time (min) = [when the max time is reached test will stop]
- Min. beginning DO (mg/L) = [enter the minimum level of DO allowed at the start of the test. If the DO falls below this level, test will not start]
- Min ending DO (mg/L) = [enter the minimum level of DO allowed during the test. If the DO level falls to this level, the test will end]
- Solids weight (g/L) = [Enter TSS or TVSS maximum acceptable limit= 31.999g/L]

6. After the parameters have been set, press [ENTER] to save them and return to the SOUR menu
7. Place the probe in the prepared sample and make certain no air bubbles are trapped, turn on the stirring and wait for a few seconds for the temperature readings to stabilize.
8. Press [START] to begin the SOUR measurement.
9. 5 SOUR reading can be saved by pressing [STORE] and can be reviewed again by pressing [REVIEW].
10. Pressing [SEND ON] soft key connects to computer and sends data to it.
11. Data will be sent every 15sec.
12. The instrument will display SOUR by using following formula:

$$\text{SOUR}\ \frac{\text{mg}}{\text{g}}/\text{h} = \frac{\text{DOstart} - \text{DOend}}{\text{Telapsed}} \times \frac{3600\text{sec}}{1\text{hr}} \times \frac{\text{Total volume}}{\text{Sample volume}} \times \frac{1}{\text{MLSS or MLVSS}}$$

4. Particle Size Distribution Analysis

Particle size distribution analysis and measurement is an important parameter across many industries and in research. To measure the particle size distribution by Laser scattering Particle Size Distribution Analyzer LA-300 proceed as following:

Turn on Power switch of LA-300

⬇

Wait for approximately 60 min for laser to stabilize

⬇

Turn on the power switch of PC

⬇

Double click icon for LA-300 to activate the application

⬇

Set conditions for measurement

⬇

Pump the DI (De-ionized Water) up to the mark in sample bath

⬇

Turn on the circulation pump at set speed (5rpm)

⬇

Click De-bubble

⬇

Click Alignment

⬇

Click Blank

⬇

Partial Drain the sample bath

⬇

Sample injection in sample bath

⬇

Sonication (for 3min)

⬇

De-bubble the sample

⬇

Click Alignment

⬇

Click Measure

(Measurement Result graph, data table, measurement result data and calculated results are displayed as graphs or values)

⬇

Click on **“Measurement Files”** enter “File Name” and select **“Memory Location”**and **“Save”** the file

Note

*Do Initial Alignment before any measurement. Initial alignment is done 20 mins after the power switch is turned on, it is done at least once a day

System Conditions

Click system condition in conditions menu and select following

- **Auto functions**

Remarks before measurement	No
Automatic printing	No
Automatic save	No
Auto scale after measurement	Yes

- **System condition Blanking**

Click on Blanking

No. of accumulation	10

- **Measure condition**

Sampling Time 10

U-sonic works during measurement yes

❖ **Display condition**

Select for next Measurement

Forms of distribution	Standard
R.R Index	PSL
Distribution base	Number
Axis type	Bar

❖ **Sample information**

Sample Name

4.2. Programming

If you do not want to do the measurement manually then make a program for your desired conditions and run it. For this purpose go to sequence wizard in sequence menu and click on **"Edit sequence"**. 6 Screens will appear one after the other to help to create a new sequence. Check appropriate options for each screen as given below and save this program. Now for measurement just click on **"Run Sequence program"**

Screen#1

"Wizard for Sequence" New

Screen#2

"Repeat Measurement" No

Screen#3

"Pre treatment"

Open condition File	Yes		
Feed Dispersant	Yes		
Circulation	Yes	Current speed	5rpm
Optical axis adjustment	Yes		
Blanking	Yes		
Manually feed sample	Yes		

Ultrasonic	Yes	Time	3min
Waiting after	No		
Auto-concentration	Yes		
Optical axis adjustment	Yes		

Screen#4

"Measurement"

Auto-printing after	No
Open Print Layout files	No
Automatic save	No
Repeat Measurement	No

Screen#5

"Drain and Rinse"

Drain all	No
Rinse all	No

Screen#6

"Wizard File for sequence"

Name of sequence	………..
Comment	………..
Finish	

5. Sludge Volume Index (SVI)

1. General Discussion

The sludge volume index (SVI) is the volume in milliliters occupied by 1 g of a suspension after 30 min settling. SVI typically is used to monitor settling characteristics of activated sludge and other biological suspensions.

2. Procedure

Determine the suspended solids concentration of a well-mixed sample of the suspension. Determine the 30 min settled sludge volume.

3. Calculations

$$SVI = \frac{\text{settled sludge volume (mL/L)} \times 1000}{\text{suspended solids (mg/L)}}$$

4. Precision and Bias

Precision is determined by the precision achieved in the suspended solids measurement, the settling characteristics of the suspension, and variables associated with the measurement of the settled sludge volume. Bias is not applicable.

Appendix-C

DATA COLLECTED

Appendix C

1. TSS, MLSS &MLVSS

S.No.	Date	Mixed Liqour Suspended Solids			Total Suspended Solids (TSS)			
		MLSS	MLVSS	MLVSS/MLSS	Influent	Primary-Outlet	Effluent	Removal Efficiency %
1	2-Aug	1120	877	0.783	153	148	4	97
2	27-Aug	550	422	0.767	230	210	6	97
3	31-Aug	240	178	0.742	158	143	14	91
4	2-Sep	176	149	0.847	104	98	14	87
5	8-Sep	206	174	0.845	138	121	10	93
6	15-Sep	376	296	0.787	198	157	18	91
7	20-Sep	1210	900	0.744	266	245	16	94
8	21-Sep	730	615	0.842	213	206	10	95
9	22-Sep	1176	890	0.757	322	288	16	95
10	27-Sep	2876	2310	0.803	190	173	8	96
11	4-Oct	2413	1327	0.550	183	170	7	96
12	8-Oct	3090	1742	0.564	187	163	18	90
13	13-Oct	3800	2100	0.553	200	182	20	90
14	14-Oct	4010	2450	0.611	226	206	26	88
15	15-Oct	3700	2520	0.681	235	212	20	91
16	19-Oct	3320	2063	0.621	227	163	13	94
17	28-Oct	1243	857	0.689	235	198	19	92
18	3-Nov	1343	1183	0.881	240	193	15	94
19	4-Nov	1540	1223	0.794	235	201	25	89
20	5-Nov	2403	1654	0.688	278	243	28	90
21	8-Nov	1645	1276	0.776	265	165	15	94
22	10-Nov	1754	1356	0.773	281	178	28	90
23	11-Nov	1883	1303	0.692	233	200	33	86
24	12-Nov	2025	1512	0.747	245	198	18	93
25	15-Nov	2438	1765	0.724	253	221	22	91
26	22-Nov	2790	1267	0.454	302	205	29	90
27	23-Nov	2830	1986	0.702	276	190	16	94

28	24-Nov	2913	2087	0.716	266	170	26	90
29	25-Nov	3067	2354	0.768	340	257	36	89
30	26-Nov	3103	2473	0.797	270	200	16	94
31	1-Dec	3206	2370	0.739	220	170	22	90
32	2-Dec	2860	2150	0.752	261	165	28	89
33	3-Dec	2665	2065	0.775	215	134	25	88
34	6-Dec	3505	2459	0.702	220	145	35	84
35	7-Dec	3205	2466	0.769	223	167	13	94
36	8-Dec	3275	2435	0.744	236	176	20	92
37	9-Dec	3275	2230	0.681	263	173	7	97
38	10-Dec	3370	2476	0.735	254	184	19	93
39	11-Dec	3313	2376	0.717	246	160	20	92
40	13-Dec	3421	2612	0.764	198	166	15	92
41	15-Dec	3510	2523	0.719	159	112	4	97
42	18-Dec	3723	2845	0.764	274	203	23	92
43	20-Dec	3860	2965	0.768	240	170	20	92
44	22-Dec	3130	2543	0.812	207	157	7	97
45	24-Dec	2400	1894	0.789	276	160	20	93
46	27-Dec	2700	2132	0.790	243	173	22	91
47	28-Dec	3345	2734	0.817	210	172	10	95
48	1-Jan	3550	2698	0.760	256	96	26	90
49	3-Jan	4285	3278	0.765	243	178	10	96
50	4-Jan	3815	2976	0.780	263	187	20	92
51	5-Jan	3715	2754	0.741	246	190	22	91
52	6-Jan	3815	2980	0.781	120	100	23	81
53	7-Jan	3565	2775	0.778	256	143	16	94
54	8-Jan	3540	2225	0.629	236	156	23	90
55	10-Jan	3515	2786	0.793	240	181	20	92
56	11-Jan	3500	2689	0.768	273	165	30	89
57	12-Jan	3745	2754	0.735	243	186	23	91
58	13-Jan	3835	3242	0.845	266	175	20	92
59	14-Jan	3720	2932	0.788	248	162	22	91
60	15-Jan	3600	2800	0.778	283	197	26	91
61	17-Jan	2970	2800	0.943	210	176	17	92
62	18-Jan	3105	2475	0.797	210	186	13	94

63	19-Jan	3289	2675	0.813	243	189	19	92
64	20-Jan	3400	2350	0.691	235	182	21	91
65	21-Jan	3505	2550	0.728	232	176	20	91
66	22-Jan	3580	2800	0.782	246	165	22	91
67	24-Jan	3685	2750	0.746	255	176	28	89
68	25-Jan	3470	2275	0.656	243	185	19	92
69	29-Jan	3705	2954	0.797	288	177	21	93
70	31-Jan	3420	2677	0.783	278	198	23	92
71	1-Feb	3610	2954	0.818	270	69	26	90
72	2-Feb	3435	2683	0.781	262	165	22	92
73	3-Feb	3395	2653	0.781	255	176	26	90
74	4-Feb	3530	2666	0.755	258	185	23	91
75	7-Feb	3625	2865	0.790	248	177	21	92
76	8-Feb	3405	2712	0.796	256	198	19	93
77	9-Feb	3365	2651	0.788	242	69	23	90
78	10-Feb	3275	2674	0.816	238	186	28	88
79	11-Feb	3375	2700	0.800	243	175	24	90
80	12-Feb	3425	2598	0.759	262	162	28	89
81	14-Feb	3570	2694	0.755	249	197	22	91
82	15-Feb	3315	2543	0.767	236	176	26	89
83	17-Feb	3218	2600	0.808	240	186	20	92
84	18-Feb	3432	2700	0.787	248	189	28	89
85	19-Feb	3380	2612	0.773	256	173	25	90
86	21-Feb	3518	2684	0.763	262	172	22	92
87	22-Feb	3380	2670	0.790	242	143	26	89
88	23-Feb	3290	2686	0.816	258	187	30	88
89	24-Feb	3495	2718	0.778	265	166	28	89
90	25-Feb	3365	2700	0.802	240	189	22	91

2. Temperature and pH

S.No.	Date	Influent	Primary -Outlet	Aeration Tank	Effluent	Influent	Primary -Outlet	Aeration Tank	Effluent
1	2-Aug	28	27.8	27.9	28.3	7.7	7.4	7.4	7.5
2	27-Aug	27.3	27	26.7	27.5	7.8	7.9	8.2	8.2
3	31-Aug	29.6	29.9	29.4	30.5	7.87	7.9	8	7.78
4	2-Sep	31	30.8	30.4	31.5	7.6	8	8.1	7.9
5	8-Sep	30.9	30.2	31.4	31.3	7.7	7.6	7.9	8.1
6	15-Sep	27.1	26.9	27.1	27	7.8	7.5	8	7.7
7	20-Sep	25.9	25.4	25.8	25.8	7.7	7.4	7.6	7.6
8	21-Sep	27.6	26.7	26.3	28	7.6	7.6	7.7	7.8
9	22-Sep	27	27	26.9	27	7.6	7.4	7.7	7.8
10	27-Sep	28.3	27.2	26	27.9	7.3	7.6	7.6	7.8
11	5-Oct	27.6	27.9	27	27.4	7.6	7.67	7.6	7.7
12	7-Oct	26.7	26.4	27	26.6	6.5	7.3	7.3	7.3
13	13-Oct	26.2	26	26	26.3	6.9	6.7	6.9	7.2
14	14-Oct	25.8	25.8	25.7	25.7	7.5	7.5	7.6	7.4
15	15-Oct	26.2	26.2	26.3	26	7.6	7.6	7.5	7.7
16	21-Oct	26	26	26	25.9	7.7	7.7	7.7	7.8
17	28-Oct	22.7	23	22	23	7.8	7.9	7.9	7.9
18	3-Nov	22	22.5	21.9	22	7.5	7.5	7.6	7.4
10	4-Nov	21	22.4	21.8	22	7.8	7.4	7.5	7.9
20	5-Nov	21	20.4	20.8	21	7.7	7.4	7.9	7.1
21	8-Nov	20	20.3	20.5	20.8	7.6	7.67	7.6	7.7
22	10-Nov	21	21.9	21.3	21	7.3	7.6	7.6	7.8
23	11-Nov	20	20	19.7	20.4	7.5	7.9	7.7	7.9
24	12-Nov	20	19.8	20.2	20.4	7.2	7.5	7.5	7.3
25	15-Nov	19	18.5	18.9	19	7.2	6.9	6.9	7
26	22-Nov	19	18.7	19	19.2	7.4	7.2	7.1	7.3
27	23-Nov	19.6	19.4	19.6	19	7.7	7.7	7.6	7.6
28	24-Nov	19.2	19.6	19.5	19.3	7.8	7.8	7.5	7.7
29	25-Nov	20.6	20.5	19.4	20.4	7.05	7.03	7.13	7.03
30	26-Nov	19.6	19.8	20.3	19.2	7.7	7.9	7.5	7.5
31	1-Dec	19.2	19.5	18.6	19.5	7.4	7.2	7	7.3
32	2-Dec	19.6	19.4	19.6	19	7.9	7.7	7.4	7.6

33	3-Dec	19	19	17	18	8	7.9	7.7	7.8
34	6-Dec	14.8	14.8	17.1	14.7	7.6	7.55	7.6	7.4
35	7-Dec	18.6	19.8	17.2	19.4	7.8	7.5	7.9	7.7
36	8-Dec	18.5	18.8	17.3	18.6	7.7	7.7	7.5	7.6
37	9-Dec	17.5	17.2	16.8	16.6	7.9	7.9	7.6	7.8
38	10-Dec	17.2	17.6	16.2	17	7.7	7.7	7.4	7.4
39	11-Dec	19.7	19.9	19.5	19.9	7.4	7.5	7.8	7.6
40	13-Dec	18.2	18	17.6	18.8	7.7	7.4	7.8	7.4
41	15-Dec	18.7	19.2	18.4	19.5	7.9	7.5	7.6	7.4
42	18-Dec	18.4	19.1	18.3	19.5	7.5	7.4	7.6	7.3
43	20-Dec	18.6	19.8	18.4	19.7	7.7	7.2	7.9	7.4
44	22-Dec	16.3	16	15.6	14	7.3	7.3	7.7	7.6
45	23-Dec	16.4	16	15.9	16.2	7.6	7.5	7.1	7.3
46	27-Dec	16.7	16.9	15.7	16.5	7.9	7.4	8	7.7
47	28-Dec	15.3	15.7	15	16	7.2	6.9	7.7	7.3
48	1-Jan	14.7	14.6	14.6	15	7.7	7.8	7.6	7.5
49	3-Jan	16.5	16.4	16.9	16.7	7.6	7.7	7.5	7.4
50	4-Jan	16.6	16.6	16.4	16.7	7.7	7.6	7.4	7.5
51	5-Jan	15.9	15.8	16.2	16	7.8	7.8	7.6	7.6
52	6-Jan	16	16.3	16.1	16.8	7.9	7.6	7.8	7.4
53	7-Jan	16	16	15.7	16.2	7.6	7.6	7.5	7.5
54	8-Jan	15.9	16	15.2	16	7.9	7.9	7.6	7.7
55	10-Jan	16.5	16	16	16.2	7.8	7.8	7.7	7.5
56	11-Jan	16.2	16.1	16.5	16.7	7.7	7.7	7.9	7.3
57	12-Jan	16.4	16.3	16.2	16	7.9	7.9	7.6	7.8
58	13-Jan	16.5	16.3	16.2	16.4	7.8	7.8	7.5	7.6
59	14-Jan	16	16.3	16	16.2	7.9	7.8	7.6	7.7
60	15-Jan	15.9	16.1	16.1	16.2	7.7	7.6	7.3	7.5
61	17-Jan	17.2	16.9	16.2	16.5	7.5	7.7	7.2	7.9
62	18-Jan	16	16.4	15.9	16.2	7.9	7.5	7.6	7.7
63	19-Jan	15.9	15.8	15.5	16.3	7.8	7.7	7.5	7.6
64	20-Jan	15.9	15.8	16.2	16	7.8	7.8	7.6	7.6
65	21-Jan	16	16.2	16.1	16	7.9	7.9	7.5	7.6
66	22-Jan	16.5	16.1	16	16.2	8	7.9	7.7	7.9
67	24-Jan	16	16.4	16.2	16.5	7.8	7.6	7.6	7.9

68	25-Jan	17.4	17.2	16.4	16.8	7.5	7.5	7.4	7.7
69	26-Jan	16.4	16.1	16	16.3	7.8	7.8	7.7	7.5
70	27-Jan	16.4	16.3	16.2	16.1	7.7	7.7	7.9	7.3
71	28-Jan	16.2	16.4	16.2	16	7.9	7.9	7.6	7.8
72	29-Jan	16.3	16	16.2	16.1	7.8	7.8	7.5	7.6
73	31-Jan	16.5	16.2	16.4	16.2	7.9	7.8	7.6	7.7
74	1-Feb	16.4	16.2	16.3	16	7.7	7.6	7.3	7.5
75	2-Feb	17.2	17	16.9	16.8	7.5	7.7	7.2	7.9
76	3-Feb	17	17	16.8	16.5	7.9	7.5	7.6	7.7
77	4-Feb	16.9	16.4	16	16	7.7	7.6	7.4	7.5
78	7-Feb	16	16	16	16.2	7.8	7.8	7.6	7.6
79	8-Feb	15.9	16	15.8	15.8	7.9	7.6	7.8	7.4
80	9-Feb	16.2	16.4	16.2	16	7.6	7.6	7.5	7.5
81	10-Feb	16	15.9	15.8	15.9	8	7.9	7.7	7.9
82	11-Feb	16	16.2	15.8	15.8	7.8	7.6	7.6	7.9
83	12-Feb	15.9	15.8	15.6	15.6	7.5	7.5	7.4	7.7
84	14-Feb	16.2	16	15.9	16	7.8	7.8	7.7	7.5
85	15-Feb	16.5	16.2	16	16	7.7	7.7	7.9	7.3
86	17-Feb	16.4	16.3	16.1	16	7.9	7.9	7.6	7.8
87	18-Feb	16	16.2	15.9	15.8	7.8	7.8	7.5	7.6
88	19-Feb	16.4	16.2	16	16	7.7	7.7	7.6	7.6
89	21-Feb	16.2	16.5	16	16	7.8	7.8	7.5	7.7
90	22-Feb	17.2	16.6	16.5	16	7.05	7.03	7.13	7.03
91	23-Feb	17	16.8	16.6	16.6	7.7	7.9	7.5	7.5
92	24-Feb	16.5	16.2	16	16	7.4	7.2	7	7.3
93	25-Feb	17.2	17	16.8	16.4	7.9	7.7	7.4	7.6

3. Chemical Oxygen Demand (COD)

S.No.	Time (Days)	Influent	Out-Primary	Effluent	Removal Efficiency (%)
1	10	268.8	304	115.2	57
2	11	185.6	236.8	105.6	43
3	12	393.6	246.4	59.2	85

4	14	320	147.2	62.4	81
5	15	307.2	224	92.8	70
6	16	320	288	118.4	63
7	17	246.4	214.4	121.6	51
8	19	233.6	172.8	76.8	67
9	23	182.4	156.8	41.6	77
10	26	208	167	83	60
11	27	219.2	187.2	104	53
12	30	216	190.4	25.6	88
13	32	240	211	53	78
14	37	304	200	32	89
15	38	211.2	150.4	41.6	80
16	39	272	152	32	88
17	40	265	161	40	85
18	41	248	168	56	77
19	42	272	160	32	88
20	43	232	157	33.6	86
21	44	352	208	64	82
22	45	252.8	174	76	70
23	46	272	160	96	65
24	47	240	171	32	87
25	49	246	164	36	85
26	50	265	85	48	82
27	52	288	224	64	78
28	53	286	176	80	72
29	54	264	189	56	79
30	55	192	83.2	36.8	81
31	56	272	102	62	77
32	57	260	123	42	84
33	58	252	165	36	86
34	59	256	156	40	84
35	60	248	198	42	83
36	61	272	224	64	76
37	62	288	256	64	78
38	63	275	189	51	81
39	64	242	174	36	85

40	65	260	210	46	82
41	66	269	221	41	85
42	67	232	187	38	84
43	68	268	201	68	75
44	69	272	197	56	79
45	70	268	192	48	82
46	71	242	189	46	81
47	72	242	165	46	81
48	73	256	176	48	81
49	74	272	184	56	79
50	75	258	176	46	82
51	76	248	192	43	83
52	77	256	172	46	82
53	79	268	154	49	82
54	80	272	165	49	82
55	84	265	188	48	82
56	85	258	176	52	80
57	88	256	171	46	82
58	90	248	166	44	82

4. Biological Oxygen Demand (BOD)

S.No.	Time (Days)	Influent	Outlet Primary	Effluent	Removal Efficiency (%)
1	10	70.575	55.5	30.3	57
2	11	75.2	60.6	34.95	54
3	14	61.35	52	25.125	59
4	16	106	77	30	72
5	19	98.55	78	33.875	66
6	23	133.275	87.35	32.125	76
7	27	127.8	94.23	38.97	70
8	30	117	87.54	27.18	77
9	32	97	89	29.37	70
10	38	71.7	64	34.35	52
11	43	81.15	62.09	25.08	69
12	46	141.1	56.14	20.3	86

13	54	143	115	29	80
14	58	163.35	108.25	25.97	84
15	65	170	69.74	24	86
16	69	152	73.65	25	84
17	72	181	72	26	86
18	84	162	87	23	86