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GUIDANCE DOCUMENT ON PERFORMANCE MONITORING OF SEWAGE TREATMENT SYSTEMS

DOE Headquarters
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TECHNICAL GUIDANCE ON PERFORMANCE MONITORING OF SEWAGE TREATMENT SYSTEMS

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FOREWORD

The current pollution control strategy of the Department of Environment is a mix of command and control (C&C) and self regulation (SR) approaches. The relatively new SR approach emphasizes on the incorporation and internalization of environmental dimension into the day to day operation and business decision making process of an organization. The environmental dimension is comprehensively integrated through the application of a set of administrative and technical measures commonly referred to as the environmental mainstreaming (EM) tools. One of the activities in the overall package of EM tools is the implementation of a systematic plan of continuous monitoring, analyzing, taking corrective actions, making improvements related to the operation of the pollution control systems installed in the premise of the organization. This plan is commonly known as performance monitoring. Performance monitoring (PM) of a sewage treatment system (STS) is a proactive and preventive strategy which has the overall objective of assuring the STS is operated and maintained in an optimal fashion resulting in the production of compliant discharge at all times. PM is a "win-win" strategy, which translates into comprehensive practical measures, if implemented aggressively by the STS practitioner will improve STS regulatory, enhance corporate image of the organization, and contribute to amelioration of the water quality of our rivers.

The implementation of the activities specified in this Technical Guidance Document will generate records on STS operation, maintenance, and performance monitoring that are required to be maintained to fulfill the requirement as stipulated in regulation 20 (1) of the Sewage Regulations 2009 (commonly referred to as the SR).

This Guidance Document may be cited as STS PERFORMANCE MONITORING GUIDANCE DOCUMENT.

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Director General
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October, 2017.

CHAPTER 1:
INTRODUCTION

CHAPTER 1- INTRODUCTION

Sewage contains a variety of contaminants which include suspended, dissolved and colloidal organic matter, inorganic substances (such as nutrients in the form of nitrogen and phosphorus), and pathogenic organisms. The contaminants are removed in a sewage treatment system (STS) prior to discharge to prevent deleterious impact to the receiving environment. The STS uses a combination of biological treatment processes (BPs) and physical chemical treatment processes (PCPs) to remove the contaminants. The BPs employ different groups of microorganisms to remove dissolved and colloidal organic matter and nutrients through biochemical processes, while the PCPs utilize physical and chemical phenomena to remove inorganic substances and suspended materials. All the components of BPs and PCPs need to be operated and maintained in tip-top conditions in order for the STS to yield excellent treatment performance on a sustained basis.

The efficiency of treatment achieved by the individual treatment components of the STS depends on the processes occurring in the treatment components. The BPs and PCPs making up the STS will function in an optimal fashion if the factors controlling the unit processes and unit operations are maintained in the recommended range, established by theoretical considerations or/and empirical observations. Over the years, these factors and their recommended values have been identified and their applicability and usefulness in the STS operation have been well documented. The various activities associated with the monitoring of the factors and ensuring they are maintained in the recommended ranges is commonly referred to as "performance monitoring". Rigorous implementation of STS performance monitoring will afford a total control of the STS processes resulting in the production of quality sewage effluent discharge that complies with the discharge standards on a consistent basis. Discharge of compliant effluents protects receiving water courses, improves public's acceptability, enhances discharger's image, and increases regulatory compliance.

This Document presents general considerations and procedure on STS performance monitoring so that effective performance monitoring program can be established for the varied types of unit processes and operations typically found in an STS.

CHAPTER 2:
PURPOSE OF GUIDANCE DOCUMENT

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Recently, in order to improve its effectiveness, the pollution control strategy of the Department of Environment (DOE) which has all these years relied primarily on the command and control approach, has embraced a preventive element of self regulation approach. Self-regulation in the context of the DOE can be understood to mean that the regulated communities (or regulated sectors) have internalized and incorporated the environmental dimensions in their business, manufacturing, and decision making processes. Self-regulation (SR) complements the existing command and control (C&C) approach of the DOE. The SR initiative of the DOE comes with a package of environmental mainstreaming (EM) tools where performance monitoring of the pollution control systems is an essential part and parcel of the package. For the sewage sector, the performance monitoring of the sewage treatment systems (STSs) is now a legally required activity.

This Guidance Document primarily serves the purpose of providing a general guide to the sewage treatment system (STS) professionals on the practice of STS performance monitoring. Particularly, the Guidance Document:

(i) Identifies the relevant performance monitoring parameters for the unit operations and unit processes typically used for the treatment of sewage

(ii) Specifies the recommended ranges for the performance monitoring parameters

(iii) Stipulates the field log sheets and performance monitoring record keeping tables

(iv) Specifies performance monitoring sampling stations and frequency

(v) Provides examples of performance monitoring reports

The specifications described in this Guidance Document represent the minimum requirements on STS performance monitoring to be implemented by the STS owners in order to be compliant with regulation 20 of the EQ (Sewage Regulations) 2009 (commonly referred to as the SR).

Additionally, some aspects of STS hardware operation and maintenance are described to fulfill the requirements on proper operation and maintenance of STS components as stipulated in regulation 5 of the SR.

CHAPTER 3:
PERFORMANCE MONITORING IN A NUTSHELL

CHAPTER 3: PERFORMANCE MONITORING IN A NUTSHELL

Sewage treatment systems (STSs) used to treat sewage consist of a combination of several treatment processes employed to remove a variety of contaminants found in the raw sewage. The treatment processes are generally categorized as biological treatment systems (BPs) or physical chemical treatment systems (PCPs). Each treatment process, whether it is a BP or PCP, in turn is comprised of the "hardware components" and the "software components". Successful treatment of sewage demonstrated in quality treated sewage discharge, depends upon each component being maintained and operated in an optimal fashion. The PCP hardware components may include the equalization tank, clarifiers, coagulation tank, flocculation tank, pH adjustment tank, media filters, activated carbon adsorption column, disinfection system, mixers, aeration systems, blowers, compressors, pumps, and chemical dosing systems. Additionally, PCP hardware components also include solids handling units such as the sand bed, belt press, and filter press. The BP hardware components may include aeration tank, ponds (aerobic, anaerobic, facultative), aerobic bioreactors, anaerobic bioreactors, anaerobic digesters, and attached growth reactors. The software components refer to the processes occurring in the PCP and BP hardware components mentioned above. To achieve a smooth and uninterrupted operation and peak performance of the entire STS, both the hardware and software components must be maintained in optimal conditions. The package of interrelated activities that is systematically conducted to monitor the physical, chemical, and biochemical processes occurring in the hardware components and ensure they happen in optimal manner is known as performance monitoring. There is yet another set of activities which focuses on the monitoring of the hardware components, which is commonly referred to as hardware preventive and corrective maintenance plan. The two groups of activities, namely the performance monitoring and hardware monitoring are mutually supportive of each other, and if developed and implemented rigorously, would result in an optimal operation of the STS, producing compliant sewage effluent on a sustained basis.

3.1 Performance monitoring: process monitoring

From the general understanding of the concept of performance monitoring discussed above, the following is a summary of the major features of STS performance monitoring:

- Performance monitoring (PM) of an STS is a proactive and preventive approach to process monitoring, where each process that occurs in the treatment units is monitored, by measuring certain key process parameters, characteristic of the process, on a scheduled basis. These parameters or characteristics, commonly referred to as the performance monitoring parameters and their recommended ranges, have been identified, primarily based on the technical understanding of the processes and by years of experience.
- Performance monitoring provides a diagnostic indicator of the "health status" of the treatment processes occurring in the treatment units, obtained by comparing the monitored parameters with their recommended ranges.

3.2 Performance monitoring: action oriented procedure

Both process monitoring and hardware monitoring procedure embed an intrinsic action oriented feature where if it is observed that the PM parameters have drifted away from the recommended ranges, or the hardware is not functioning properly, immediate corrective actions are instituted. PM does not carry with it a "passive" connotation, but instead, "aggressive" responses are expected to be taken by the facility owner to fix "out of the range" situations.

3.3 Hardware monitoring

Hardware monitoring can be summarized as follows:

- Hardware monitoring translates into the implementation of preventive and corrective maintenance plans for the entire hardware components of the STS.

Hardware monitoring is a well-established concept whose importance is well understood by the management and STS practitioners and is implemented satisfactorily in most premises. On the hand, performance monitoring is less understood and relatively less appreciated, hence its implementation is generally sporadic, unsystematic, and is implemented in a lackadaisical manner.

3.4 Compliance monitoring

Performance monitoring focuses on the monitoring of the processes in the treatment components while compliance monitoring emphasizes on the effluent quality achieved by the sewage treatment system as a whole, at the discharge point. Performance monitoring (PM) gathers process information to establish the health status of a treatment component and diagnose process upsets. PM is a preventive strategy that gives early warning of impending process upsets enabling corrective actions to be taken promptly, hence averts total IETS failure. Compliance monitoring with its discharge point focus suffers from an inherent disadvantage of "too late situation" where serious process upset may have occurred which may result in noncompliant effluent discharge.

CHAPTER 4:
REGULATORY REQUIREMENTS ON PERFORMANCE MONITORING

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The requirement on performance monitoring of sewage treatment systems (STSs) is stipulated in regulation 20 (1) of the Sewage Regulations 2009 (commonly referred to as the SR). The procedure and specifications on STS performance monitoring stipulated in this Guidance Document represent the minimum that the owners of STSs need to implement in order to be in compliance with the above regulatory requirement. Specifically, regulation 20 requires the STS owners or occupiers to maintain records of operation, maintenance, and performance monitoring of the STS, which can serve the purpose of planning and management and for ensuring continued discharge compliance.

4.1 STS hardware operation and maintenance records

STS hardware maintenance is an integral part of the operation of an STS that ensures the structural, mechanical, and electrical components are in working conditions all the time. This important aspect of the O&M of the STS translates into the preventive and corrective maintenance plan which would prevent hardware failures which may lead to process failures resulting in noncompliant sewage effluent discharge. Ensuring all STS components are working in an acceptable condition is a legal requirement under regulation 5 of the SR. A preventive and corrective O&M plan must be prepared and implemented and records of O&M for each component maintained for facilities management planning and the inspection by the DOE inspectors.

4.2 STS performance monitoring records

As explained in Chapter 3, performance monitoring refers to the monitoring of the physical, chemical, and biological processes occurring in the various treatment components of the entire STS. The performance monitoring activities and parameters relevant to each STS must be identified and wherever applicable, the recommended range for the parameters specified. The PM activities are then implemented on a scheduled basis and the records are required to be maintained in a suitable format as recommended in this Guidance Document. Daily records which may be in the form of hand written entries in field log sheets, are required to be summarized in a graphical format at the end of each calendar month. Data analysis is discussed in chapter 15 of this Guidance Document.

CHAPTER 5:

GENERAL CONSIDERATIONS ON PERFORMANCE MONITORING OF SEWAGE TREATMENT SYSTEMS

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A sewage treatment system performance monitoring plan (STSPMP) is prepared to describe the details of the performance monitoring activities to be carried out at the premise of a sewage treatment system (STS). The STSMP is a site-specific plan that takes into consideration the type and size of the STS, availability of performance monitoring equipment, staffing requirement, sampling and analytical needs, data processing, and reporting requirements. A separate STS operation and maintenance document must be prepared to detail out the preventive and corrective plans to ensure the hardware components of the entire STS are maintained in optimal conditions at all times. The chapter is dedicated to the discussion of the general considerations, features, and activities that must be described and explained in the STSMP while the STS hardware O&M aspects are discussed in different chapter.

The STSPMP describes the following elements:

- Sampling plan which identifies the sampling stations, sampling parameters, sampling frequency, sample type
- Staff involved in carrying out the sampling tasks, sample preservation and laboratory analysis
- Equipment readings and field log sheets
- Performance monitoring equipment
- Accredited laboratory to which STS samples will be sent for analysis
- Data analysis
- Reporting

The details are described below.

5.3 Sewage sampling and analysis plan

5.3.1 Sampling stations

The sampling locations must be selected to meet the following general criteria:

(i) Samples taken from the sampling stations must be representative. To ensure good mixing, samples are preferably sampled at points of highly turbulent flow.

(ii) Location of sampling stations must be safe and easily accessible

The sampling stations comprise both categories of stations: those for performance monitoring purposes and the one used for compliance monitoring.

5.3.2 Sewage influent monitoring

Routine sewage influent monitoring is performed to quantify the load that is received by the sewage treatment system (STS). Typically, the incoming raw sewage is monitored for its flow and quality and from the data obtained the incoming organic loading rates, in-plant return flows and chemical feed rates can be calculated.

Whenever possible and where it is not burdensome economically, on-line continuous measurement of the performance monitoring (PM) should be implemented. Typical PM parameters amenable to on-line monitoring include temperature, pH, dissolved oxygen, ammonia, nitrate, oxygen uptake rate (OUR), chemical oxygen demand (COD), and total suspended solids (TSS).

5.3.3 Sewage effluent monitoring

Monitoring of sewage discharged through the final discharge point (FDP) final discharge point (FDP) is required under regulation 10 of the Sewage Regulations 2009 (SR). This is commonly referred to as compliance monitoring. Apart from flow, the sewage effluent parameters include pH, temperature, BOD, COD, SS, AN, NO_3-N, and O&G. The quality of the final effluent must comply with the discharge standards all the time. On-line monitoring of sewage effluent parameters such as pH, COD, NH_3, NO_3- and TSS may be also performed to obtain discharge compliance on a real time basis. The STS owners are required to maintain and submit monthly discharge monitoring reports (MDMR) to the DOE to demonstrate compliance with the discharge standards. The on-line reporting of discharge information is commonly known as the On-line Environmental Reporting (OER), which is applicable to all types of effluent discharges such as sewage, industrial effluents and leachate.

5.3.4 Sample type and preservation

For the purpose of performance monitoring, composite sampling may be used for some parameters such as BOD and TSS. For compliance monitoring, grab sampling must be used. Preferably, samples shall be analyzed as soon as possible. If necessary, preservation protocols recommended in the Standard Methods must be adhered to. Parameters such as pH, D.O. and temperature shall be measured in-situ.

5.3.5 Analytical requirements

5.3.5.1 Performance monitoring

The regulated communities discharging sewage are encouraged to use rapid testing methods to obtain the required information for the purpose of conducting performance monitoring of the STS. The effluent quality analysis is accomplished by in-situ measurements using portable equipment widely available in the market. Equivalent methods modified from the Standard Methods are totally acceptable. The regulated communities are encouraged to provide facilities, relevant equipment, or instruments for the purpose of conducting performance monitoring. An on-site laboratory equipped with basic facilities to conduct routine measurements and equipment calibration would facilitate the conduct of STS performance monitoring in a technically conducive environment.

5.3.5.2 Compliance monitoring

For the purpose of compliance monitoring, treated sewage samples at the FDP must be sent for analysis to the accredited laboratories, which are regulated by the Standards Department. The analytical methods used by the laboratories need to follow the procedures specified in the Standard Methods.

5.4 Flow measuring devices

The need for monitoring both the influent sewage and the treated sewage flowrates has been mentioned in subparagraphs 5.3.2 and 5.3.3. Flowrate measurements can be made by using any of the flow rate meters, which are available in various types in the market. The use of digital flow meters is generally preferred but alternatively, in limited cases, other flow measuring devices such as orifice plate, weirs, or V notches can also be used. The type of flow meter chosen shall be appropriate for its application.

5.5 Trained personnel

Technical personnel assigned with performance monitoring (PM) tasks such as effluent sampling and analysis, performance monitoring instrument readings, data analysis, instrument calibrations and maintenance, etc. must be adequately trained to perform the assigned tasks. Dedicated training courses which can be done in-house, must be identified and implemented for this purpose.

5.6. Data management

The performance monitoring data such as instrument reading, laboratory records, or calculated parameters, may be initially recorded in a hand written form by the field technicians or laboratory staff. The PM data is required to be summarized and presented in an easy to understand format such as the graphical form, and the task must be accomplished within a thirty days after each calendar month.

5.7 Record keeping

The legal requirement on record keeping of performance monitoring data is elaborated in chapter 19 of this Guidance Document.

CHAPTER 6:
TYPICAL COMPONENTS OF SEWAGE TREATMENT SYSTEMS

CHAPTER 6: TYPICAL COMPONENTS OF SEWAGE TREATMENT SYSTEMS

This Chapter describes briefly the typical treatment processes that are utilized for removing the contaminants from sewage, which are present in suspended, colloidal, and dissolved forms.

6.1 Physical chemical treatment processes and biological treatment processes

Sewage treatment processes may be grouped into two general categories, the first being physical-chemical processes (PCPs). This category includes screening, sedimentation, filtration, precipitation, adsorption, chemical oxidation, and irradiation. The PCPs utilize physical or chemical processes to remove contaminants from sewage. The second category is generally described as biological processes (BPs) which include several processes which rely on microbial processes carried out microorgansms to remove pollutants from the sewage. The BPs include processes such as waste stabilization lagoons, trickling filters, rotating biological contactors, and activated sludge systems.

6.2 Preliminary, primary, secondary, and tertiary treatment stages

Viewed from the perspective of stages of treatment, sewage undergoes preliminary treatment, primary treatment, secondary treatment, and tertiary treatment before the treated sewage is fit for discharge to the environment. Preliminary treatment is typically physical in nature which is used to remove large debris and grit by using coarse and fine bar screens and grit chambers. Primary treatment is also physical in nature which is employed to remove settleable suspended solids (TSS). Secondary treatment is biological in nature which is utilized to remove dissolved and colloidal organic matter by the help of microorganisms. Tertiary treatment generally involves physical or chemical processes to remove nutrients, residual fine particulates, dissolved organics and color.

6.3 The sewage treament systems-combination of PCPs and BPs

A typical flowchart of a sewage treatment system (STS) employing a combination of physical-chemical treatment processes (PCPs) and biological treatment processes (BPs) is shown in Fig. 6.1. Processes assigned number 1, 2, and 4 in Fig. 6 are physical in nature while number 3 and 7 are biochemical in character. 5 can either be a physical or a chemical process while 8 is a chemical process.

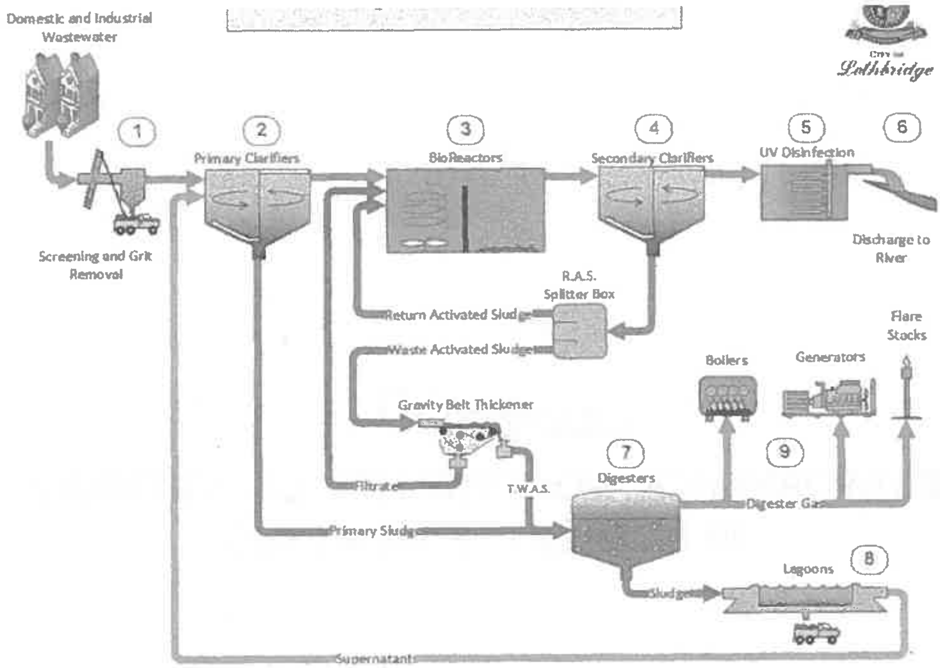

Fig. 6.1: Example of a flow chart of a sewage treatment system (source: Leithbridge city, 2017)

As discussed earlier, the processes are categorized into three categories: primary processes (which also include preliminary and pretreatment processes), secondary processes, and tertiary processes. In the subsequent chapters, the PM requirements and procedures for each treatment process in all categories will be discussed as it appears in the flowchart. The discussion starts with the primary processes in Chapter 7, followed by the secondary processes in Chapter 8, and the tertiary processes in Chapter 9. The discussions will automatically cover all the STS types mentioned in the Sewage Regulations, namely the ponding systems (oxidation ponds, aerated lagoons), the suspended growth systems (activated sludge systems, sequencing batch reactors, oxidation ditches), and the attached growth systems (trickling fliters, rotating biological contactors).

CHAPTER 7:

PERFORMANCE MONITORING OF PRIMARY TREATMENT PROCESSES

CHAPTER 7: PERFORMANCE MONITORING OF PRIMARY TREATMENT PROCESSES

In this Guidance Document the discussion of performance monitoring of primary treatment processes also includes the preliminary treatment processes. Preliminary treatment processes include screening of floatables and separation of sand and grit from the raw sewage. Pretreatment includes preaeration to reduce septicity and flow equalization to minimize random or cyclic peaking of organic or hydraulic loadings. Primary treatment process removes suspended solids by gravity separation before sewage is subject to biological treatment in the secondary treatment processes. Primary treatment achieves not only removal of total suspended solids (TSS), but organic matter removal is also accomplished through primary treatment because the TSS removed includes the organic solids. As a result, biochemical oxygen demand is also reduced. Primary treatment is in essence primary clarification of sewage by removing its TSS via the use gravity clarifiers. This chapter also includes a discussion of low cost treatment processes, which provide limited treatment of sewage through solids settling and anaerobic biodegradation processes.

7.1 Performance monitoring of primary treatment processes

Primary treatment processes comprised of preliminary, pretreatment and primary clarification, utilize physical phenomena to achieve their objective of removing the floatables, grit and large suspended solids. The processes do not involve the use of process variables such as pressure, temperature, biological or chemical reactions. Performance monitoring of these preliminary treatment processes, which, translates into more of physical maintenance of the equipment involved, rather than actual monitoring of process (performance monitoring) parameters. Some aspects of performance monitoring of the primary treatment processes are highlighted in the following sections.

7.2 Preliminary treatment

7.2.1 Physical screening and settling

Preliminary treatment processes of physical screening and settling are accomplished by using coarse and fine screens and grit chambers. Although preliminary treatment is not the most glamorous part of the sewage treatment system (STS), it plays a crucial role in sewage treatment in ensuring the downstream treatment processes run uninterruptedly. Manually cleaned screens or mechanically cleaned screens need to be inspected and maintained and grit removed from screens must be disposed of regularly.

7.3 Pretreatment

7.3.1 Equalization tanks

Equalization tanks (EQs) may be provided with the purpose to even out fluctuations in flow and pollutant concentrations. To prevent development of anaerobic conditions, dissolved oxygen (DO) in the equalization tanks should be maintained >1.0 mg/L.

7.3.2 Preaeration

If preaeration is provided, the predesigned dissolved oxygen (DO) should be monitored and maintained. Physical observation of the color of sewage and detection of odorous emission at the site should also be made.

7.4 Primary clarification

Primary treatment is essentially primary clarification of sewage achieved by the use of primary clarifiers (or sedimentation tanks). The purpose of primary clarifiers is to remove suspended solids from raw sewage. The clarifiers are designed to treat a certain amount of sewage, which is refered to as loading. For primary clarifers, loading is expressed in terms of hydraulic loading. The clarifier performance monitoring parameters described below need to be monitored on a scheduled basis to ensure optimum performance of the clarifer. Other parameters include flowrate and clarifer's inlet and oultet SS and BOD.

7.4.1 Detention time

Hydraulic detention time, or simply detention time (DT or denoted as θ) is an expression of hydraulic loading, indicating how long the sewage takes from the clarifier entry point (influent) to the exit point (effluent).

The formula for calculating HRT is

$$DT = \frac{V}{Q}$$

Where:

DT = clarifier detention time, h

V = clarifer volume, m^3

Q = sewage influent fow rate, m^3/h

The recommended DT for primary clarifiers is between 1.5 to 2.5 hours.

7.4.2 Surface overflow rate

Surface overflow rate (SOR) is an areal loading which expresses the amount of sewage applied to the clarifier's surface area. SOR is calculated by using the formula

$$SOR = \frac{Q}{A}$$

Where:

SOR = surface overflow rate, $m^3/(m^2 .d)$

A = clarifer surface area, m^2

The recommended SOR for primary clarifiers ranges from 30 to 50 $m^3/(m^2 .d)$ at Q_{max} and 80 to 120 $m^3/(m^2 .d)$ at Q_{avg}.

7.4.3 Solids removal efficiency

By comparing the influent solids concentration and the effluent solids concentration, the calrifier's solid removal efficiency can be calculated. The removal efficiency is

$$\text{TSS removal efficiency} = \frac{TSS_{in} - TSS_{out}}{TSS_{in}}$$

Where:

TSS removal efficiency = total suspended solids removal efficency, %

TSS_{in} = influent total suspended solids, mg/L

TSS_{out} = effluent total suspended solids, mg/L

Similarly, BOD removal efficiency can also ne computed.

The expected performance of primary clarifiers is 40 to 60% TSS removal and 25 to 35% BOD removal.

7.4.4 Overall performance monitoring of primary treatment process

The flowrate, TSS, and BOD of the clarifier's influent and effluent are monitored on a scheduled basis, preferably everyday. From these data, the hydraulic detention time (or hydraulic loading rate), surface overflow rate, and suspended solids and BOD removal efficiency are computed and the values are then compared with the design values. Assessment of the clarifier performance can then be made based on the comparison. Typical performance of primary treatment as summarized in Table 7.1.

Table 7.1: Typical design and operating performance of primary treatment

Design and operational parameter	Typical value
TSS removal efficiency, %	40 to 60
BOD removal efficiency, %	25 to 35
SOR, $m^3/(m^2.d)$ At Q_{av} At Q_{peak}	 80 to 120 30 to 50
DT, h At Q_{av} At Q_{peak}	 2.0 to 3.0 1.0 to 1.5

7.5 Imhof tanks and communal septic tanks

Imhoff tanks and communal septic tanks are considered as on site, low cost secondary systems which provide only partial treatment of sewage. The quality of treated effluent from these systems does not come close to the stipulated regulatory discharge standards of the DOE. Under anaerobic environment existing in the tanks, both solids which settle out in the tanks and the tank contents, undergo anaerobic biodegradation processes which accomplish about 50% reduction in BOD and TSS. The hydraulic detention time of the tanks ranges from 1 to 4 days.

7.5.1 Performance monitoring

There are minimal performance monitoring requirements for the Imhoff tanks and communal septic tanks. The requirements translate into physical maintenance of the system which includes desludging of the tanks, at a minimum, once in two years.

CHAPTER 8:
PERFORMANCE MONITORING OF LAGOON SYSTEMS

CHAPTER 8: PERFORMANCE MONITORING OF LAGOON SYSTEMS

Lagoon systems may include a series of lagoons comprising anaerobic lagoons followed by facultative or aerobic lagoons. The term lagoons and ponds are used interchangeably and carry exactly the same meanings. This chapter is dedicated to the discussion of performance monitoring requirements for these lagoons. Due to long retention time and hence large space requirements, and possibility of emission of objectionable odors, the use of anaerobic lagoons for sewage treatment is not popular in Malaysia. Comparatively, the demand on performance monitoring requirements of ponding systems is not as rigorous as that of other biological treatment systems such as the activated sludge process. However, lagoon systems too require daily inspection and maintenance which comprises a range of activities such as effluent sampling, performing basic loading calculations, maintaining the lagoons' mechanical components, and performing general operation and maintenance functions. The relevant formulas used in the calculation of some of the performance monitoring parameters for lagoon systems are given below. Typical design and operating ranges are also specified. Performance monitoring aspects are discussed in section 8.8.

8.1 General design criteria and operating parameters for lagoon systems

The following are some general design criteria typically used in the design of lagoons. The same criteria can be used at the operation stage for performance monitoring purposes and to assess the lagoons' performance.

8.1.1 Organic loading rate

Organic loading rate (OLR) is calculated using the formula:

$$OLR = \frac{Q \times BOD_{in}}{V}$$

Where:

OLR = Organic loading rate, kg/(m^3 .d).

Q = Influent flow to the lagoon, m^3/d

BOD_{in} = Influent BOD, mg/L

V = Volume of lagoon, m^3

The recommended OLRs for anaerobic lagoons are between 0.04 to 0.30 kg/(m^3 .d), while for facultative lagoons, the recommended areal OLRs range from 15 to 180 kg/(ha .d). The OLR for aerobic lagoons depends on a case to case basis according to the influent BOD and desired effluent BOD, and is typically computed using a first order kinetics and the complete mix model.

8.1.2 Detention time

Detention time (DT) or hydraulic retention time (HRT) is calculated using the formula:

$$DT = \frac{V}{Q}$$

Where:

DT = Lagoon detention time, d

V = Volume of lagoon, m^3

Q = Influent flow to the lagoon, m^3/d

Typical DT for anaerobic lagoons ranges from 1 to 50 d. Higher temperatures require less DT. For facultative lagoons, typical DT ranges from 20 to 200 d while for aerobic lagoons the DT ranges from 10 to 30 d. The DT in the settling basin or part of the lagoon used for settling should not be more than 2 days to limit algal growth.

8.1.3 Dissolved oxygen

Dissolved oxygen (DO) requirements depend on the type lagoons used. Anaerobic processes are performed by anaerobic bacteria, which prefer to work in conditions of absence of oxygen. Zero mg/L DO should be maintained and a heavy scum blanket may help to achieve this. For aerobic processes occurring in aerobic lagoons, the DO needs to be maintained in the range of 2.5 to 3.5 mg/L for organic matter removal and nitrification processes. A bare minimum of 1.0 mg/L DO throughout the pond at heaviest loading periods must be maintained.

8.1.4 pH

The pH in the anaerobic ponds should preferably be maintained at or near neutral (pH = 7). A pH range of 6.7 to 7.4 may be acceptable. When pH falls below 6.7, the methanogenisis reaction, which principally converts the organic acids to methane, will be seriously affected. For aerobic processes too, a pH range of 6 to 8.5 is required for optimal operation of the aerobic lagoons.

8.1.5 Volatile acids

Volatile acids are produced in anaerobic biodegradation processes, which could result in a pH drop. Volatile acids in anaerobic lagoons should be monitored and their concentration should preferably be less than 250 mg/L, although a higher value of 500 mg/L can be tolerated. However, a maximum concentration of 2,000 mg/L should never be exceeded. (Note: Volatile acids are measured as mg/L acetic acids).

8.1.6 Alkalinity

Alkalinity measures the buffering capacity of an effluent to resist a pH change. Alkalinity should be measured in anaerobic lagoons and maintained preferably in the range of 2,000 to 3,000 mg/L, although a range of 1,000 to 5,000 mg/L may still be acceptable (Note alkalinity is measured as mg/L $CaCO_3$).

8.1.7 Ammonia

For anaerobic lagoons, free ammonia and ammonium ions should preferably be less than 1,540 and mg/L 3,000 mg/L, respectively.

8.1.8 Oxygen reduction potential

Oxygen reduction potential (ORP) values reflect the conditions in the lagoons where positive values indicate oxidizing environment while negative values indicate anaerobic environment. In aerobic lagoons, the expected ORP values typically range from +50 mV to +250 mV where it indicates carbonaceous BOD reaction is occurring. If nitrification is also occurring, the ORP values should be between +100 mV to +350 mV. In the anaerobic lagoons, the ORP values are expected to be negative, with the values ranging from -40 mV to -250 mV, indicating the occurrence of acidogenesis reaction (organic acids formation) and -175 mV to -400 mV, indicating the occurrence of methanogenesis (release of methane gas).

Anaerobic lagoons

The primary purpose of the anaerobic lagoons is to allow preliminary sedimentation of suspended solids as a pretreatment process. Typically, the anaerobic lagoon is preceded by a bar screen and may be equipped with a flow measuring device such as a Parshall flume. Some operators prefer to let a dense scum develop over the entire lagoon's surface to keep the lagoon anaerobic and reduce odorous emission. In other cases, the lagoon may be provided with surface aeration at the lagoon's surface to minimize scum formation and control odors.

8.2 Performance monitoring requirements

Typical performance monitoring requirements for anaerobic lagoons include the following:

(i) Monitoring the BOD of the lagoon's influent and effluent
(ii) Monitoring the temperature of the lagoon
(iii) Monitoring the pH of the lagoon
(iv) Monitoring the lagoon's alkalinity
(v) Monitoring the volatile acids
(vi) Recording the influent flow rate which will be used to calculate the DT
(vii) Making observation of the scum thickness and extent of coverage of the lagoon's surface

8.2.1 Performance monitoring frequency

Preferably, daily grab samples of lagoon liquor should be taken for analysis.

8.3 Operation and maintenance

Apart from conducting performance monitoring, the following activities should be performed according to a predetermined schedule or as needed:

- Carrying out general housekeeping of the lagoons which includes checking for embankments structural integrity, grass cutting, etc.
- Maintaining mechanical components (piping system, diversion boxes, screens) and other mechanical equipment
- Measuring sludge depth (annually). Desludging is typically carried out once in 5 to 10 years.

8.4 Anaerobic lagoons treatment performance

Anaerobic lagoon effluent should have a TSS range between 80 to 160 mg/L and a black color of the lagoon contents is indicative of its proper functioning. 60% BOD removal may be achieved in anaerobic ponds.

Facultative lagoons

Facultative lagoons are used to further remove the organics in the anaerobic lagoon effluents via a combination of microbial processes and algal photosynthetic processes. Facultative lagoons should have a deep green sparkling color in the primary lagoon and high dissolved oxygen (DO) levels in the secondary or final cells.

8.5 Performance monitoring requirements

Typical performance monitoring requirements for facultative ponds include the monitoring of the following parameters of the lagoon's effluent: flowrate, BOD, pH, DO, and TSS. Preferably, daily grab samples of lagoon effluent should be taken for analysis.

8.6 Operation and maintenance

In addition to conducting performance monitoring, the following activities should be performed for general maintenance of the facultative lagoons:

- Inspecting earthen structures used for impoundments by using riprap, broken concrete rubble or a poured concrete erosion pad wherever relevant
- Maintaining wave action by ensuring the lagoons are free of banks or weeds in the water or tall weeds on the banks
- Mowing the grass and inspecting for insect problems
- Cleaning the inlet and outlet structures regularly to remove floating debris, scums, and thrash
- Maintaining mechanical equipment according to a preset schedule.

All lagoon operations should be listed on a posted schedule. Maintenance records should be kept and be readily accessible for review by plant personnel and for inspection by the DOE inspectors. Sludge depth should be measured annually and lagoon desludging carried out when necessary.

8.7 Facultative lagoon treatment performance

Facultative lagoons can produce treated sewage effluent with TSS range between <30 to 150 mg/L and their deep green color is indicative of intense algal growth. BOD removal performance may reach 95% and effluent BOD <30 mg/L can be achieved.

Facultative lagoons can also achieve significant removal of ammonia nitrogen and pathogen and coliforms.

Aerobic lagoons

Aerated lagoons can be of two types: partial mix or complete mix lagoons depending on the extent of mixing provided. In a partial mix system, aeration is provided only to satisfy the oxygen requirments of the system but the energy is not sufficient to maintain all the TSS in suspension. Partial mix aerated lagoons are also referred to as facultative lagoons. The complete mix lagoons are similar to the activated sludge systems except that there is no sludge recycling (i.e. return activated sludge-RAS).

8.8 Performance monitoring requirements

Performance monitoring of aerated lagoons includes the monitoring of the following parameters: dissolved oxygen (DO), total suspended solids (TSS), pH, ammonia nitrogen, and nitrate nitrogen. Dissolved oxygen (DO), pH and total suspended solids (TSS) should be measured daily, while other parameters, weekly.

8.9 Operation and maintenance

Aerated lagoons are equipped with aeration systems, hence special attention must be paid to the equipment to ensure they run smoothly without interruption. Lagoons may be aerated by using mechanical surface aerators or diffused aeration systems. Operation and maintenance (O&M) of the aeration system includes the following:

Mechanical surface aerators

- Ensure that the surface mechanical aerators produce good turbulence and a light amount of froth
- Keep large objects out of the pond to prevent damage to the aerator.

Diffused aerators

- Check the blower daily.
- Visually inspect the aeration pattern for dead spots or dead lines.
- Check for ruptures and repair them if necessary to maintain even distribution of air.

- Measure DO at several locations in the pond weekly and adjust air to maintain even distribution.

Periodic inspection of the earthen structures used as impoundments must be performed to ensure their structural integrity, which may be affected by inclement weather or rodent damage.

8.10 Aerobic lagoon performance

Aerated lagoons are more energy intensive and require less area than facultative lagoons and produce better level of treatment. BOD removal in aerated lagoons can range up to 95%. If settling is incorporated at the end of the lagoon system, aerobic lagoons are expected to reliably produce a treated sewage effluent BOD and TSS of less than 30 mg/L. Significant removal of coliforms may happen and nitrification will also occur if adequate oxygen is available. Aerated lagoons may have a service life up to 30 years before desludging is required.

8.11 General considerations in lagoon desludging

When it becomes necessary to desludge a lagoon (anaerobic, facultative or aerobic), the required written permission must be obtained from the DOE as stipulated in regulation 15 of the Sewage Regulations. A desludging plan outlining the method of sludge removal, steps to be taken to ensure lagoon integrity (liner, embankments), test of the sludge to be removed for volatile solids and metals, and proposed ultimate disposal of the sludge.

8.12 Record keeping requirements

Lagoon performance monitoring and maintenance records must be systematically kept and be readily accessible for internal review by the facilities personnel and for the inspection by the DOE officers.

CHAPTER 9:
PERFORMANCE MONITORING OF ATTACHED GROWTH SYSTEMS

CHAPTER 9: PERFORMANCE MONITORING OF ATTACHED GROWTH SYSTEMS

Attached growth systems are characterized by the provision a medium for the microorganisms to attach themselves to and grow and develop into a biological slime layer. The two commonly known attached growth (or fixed film) systems are the trickling filters (TFs) and the rotating biological contactors (RBCs). This chapter is dedicated to the discussion of the performance monitoring requirements of the TFs and RBCs.

The trickling filters (TFs)

9.1 Design and operating criteria

The following calculations are relevant to the design and operation of trickling filters: hydraulic loading rate, organic loading rate, and recirculation ratio. These are briefly highlighted below.

9.1.1 Hydraulic loading rate

Hydraulic loading rate (HLR) is an expression that indicates how much sewage is loaded to the cross sectional surface area of the filter.

The formula for calculating θ is

$$HLR = \frac{Q}{A}$$

Where:

HLR = filter's hydraulic retention time, h

Q = sewage influent fow rate, m^3/h

A = media top surface area, m^2

Typical loading rate for TFs is 1 to 4 $m^3/(m^2 .d)$ for low rate filters and 10 to 40 $m^3/(m^2 .d)$ for high rate filters.

9.1.2 Organic loading rate

In the design and operation of trickling filters, a loading parameter called the organic loading rate (OLR) is used. The formula for calculating the OLR is:

$$OLR = \frac{Q\,(BOD_{in})}{V_f}$$

Where:

OLR = Organic loading rate, kg BOD/(m^3.d)

Q = Influent flowrate, m^3/d

BOD_{in} = Influent BOD, mg/L

V_f = Filter media volume, m^3

$$= \frac{\pi D^2\,(H)}{4}$$ (where D = TF diameter, m; H = TF height, m)

OLR is commonly expressed in the units of kg BOD applied per 100 or 1000 cubic meters of media volume. Typical OLR may range from <40 kg BOD/(100 m^3.d) for low rate filters, up to 64 BOD/(100 m^3.d) for intermediate rate filters, and from 64 to 160 kg BOD/(100 m^3.d) for high rate filters and from 160 to 480 kg BOD/(100 m^3.d) for roughing TFs.

9.1.3 Recirculation ratio

Recirculation ratio (RR) expresses the ratio of the flowrate, which is recirculated for retreatment compared to the influent flowrate. The RR is calculated by using the formula:

$$RR = \frac{Q_R}{Q}$$

Where:

RR = recirculation ratio, %

Q_R = recirculation flow, m^3/d

Q = influent flowrate, m^3/d

Typical RR range used for sewage treatment is between 0.3 to 3.0.

9.2 Performance monitoring of trickling filters

To ensure smooth and uninterrupted operation of the trickling filters, various tests are required to be performed. The following parameters (Table 9.1) are typically monitored on a routine basis with different frequencies ranging from daily to weekly or monthly depending on normal or abnormal conditions.

Table 9.1: Performance monitoring recommendations for TFs: sampling points and parameters tested

Sampling point	Parameters
Filter influent	DO, pH, temperature, TSS, settleable solids, TSS, BOD
Recirculated flow	Q, DO, pH, temperature
Filter effluent	DO, pH, jar test
Process effluent	DO, pH, settleable solids, TSS, BOD

Another important daily task of the TF operator is to conduct physical observations of the TF. The observations to be made are summarized in Table 9.2.

Table 9.2 TF physical observations

Observation of...	What to observe	Indicates.....
Slime	Slime color	Green slime: normal. Dark green or black: Organic overload. Other colors: Chemical contamination of intrusion of industrial effluent.
	Uniformity of slime growth	Uneven or stripped slime growth: Clogged orifices or nozzles of distribution arm
Flow	Flow uniformity	Nonuniform flow: Distribution arms not level or orifices clogged
Distributor	Smooth and uniform operation and no leakage	Noisy or chattering operation: Bearing failure. Leakage: distributor seal worn out
Recirculation	Recirculation rate within design specs	RR > design rate: overloading RR< design rate: underloading
Media	Uniformity of media	Medium should be uniform

9.3 Operation and maintenance

An O&M plan must be developed and implemented for the rotary distributors and other mechanical components. Care must also be exercised to prevent leaks.

9.4 Performance of trickling filters

Trickling filters can achieve a high removal of BOD ranging from 80 to 90% for low rate TF, 50 to 70% for intermediate rate TFs and 65 to 85% for high rate TFs. High removal of ammonia and nitrate is also accomplished in TFs.

The rotating biological contactors (RBCs)

9.5 Design and operating criteria

Design and operation of RBCs involves the calculation of organic loading rate, hydraulic loading rate, soluble BOD and media area. These are briefly highlighted below.

9.5.1 Organic loading rate

The organic loading rate (OLR) for RBCs is expressed as:

$$OLR = \frac{Q\,(BOD_{in})}{A_m}$$

Where:

OLR = Organic loading rate, kg BOD/(m^2.d)

Q = Influent flowrate, m^3/d

BOD_{in} = Influent BOD, mg/L

A_m= Media area, m^2

$$= \frac{\pi D^2}{4}$$ (where D = RBC diameter, m)

OLRs for RBCs are usually expressed in kg BOD per 1000 square meters of media area per day. Typical OLRs range from 10 to 50 kg BOD/(1,000 m^2 .d)

9.5.2 Soluble BOD

Soluble BOD is calculated by using the formula

Soluble BOD = Total BOD – (K factor x Total suspended solids).

K is determined experimentally in the laboratory and for sewage, its value ranges from 0.5 to o.7.

9.6 Performance monitoring of rotating biological contactors

To assess the RBC performance and identify normal and abnormal operating conditions the following performance monitoring parameters are monitored on a routine basis. These are summarized in Table 9.3.

Table 9.3: Performance monitoring recommendations for RBCs: sampling points and parameters tested

Sampling point	Parameters
RBC influent	DO, pH, temperature, TSS, settleable solids, TSS, BOD
RBC	Speed of rotation
RBC effluent	DO, pH, jar test
Process effluent	DO, pH, settleable solids, TSS, BOD

Daily observations are also an integral part of the performance monitoring activities of the operator. Highlights of the observations are summarized in Table 9.4.

Table 9.4 RBC physical observations

Observation of…	What to observe	Indicates…..
Slime	Slime color and appearance	Gray, shaggy slime: normal. Reddish brown and golden brown: Normal nitrification process; Dark brown, shaggy growth (worms present: old sludge; White chalky growth: high sulfur level in sewage influent; No visible slime: severe pH or temperature change
Rotation	Smooth and uniform rotation	Erratic and nonuniform rotation: mechanical problems or uneven slime growth. No movement/rotation: mechanical problems or extreme slime growth

9.7 Operation and maintenance

The RBC system has many mechanical components, which need preventive and corrective maintenance. The components include a center shaft, drive system, tank, baffles, housing, cover, and a settling tank. A proper O&M plan needs to be developed and implemented for these components to ensure an uninterrupted operation of the RBC system.

9.8 Performance of rotating biological contactors

An RBC can maintain a higher biological population than in a conventional activated sludge system. As a result an RBC can be relatively small, and the effluent discharged from an RBC may have a low BOD value typically less than 20 mg/l. Significant amounts of ammonia and nitrates can also be removed in RBCs.

CHAPTER 10:
PERFORMANCE MONITORING OF SUSPENDED GROWTH SYSTEMS

CHAPTER 10: PERFORMANCE MONITORING OF SUSPENDED GROWTH SYSTEMS

The suspended growth system is dominated by the activated sludge system, which is the most widely used process in Malaysia for the treatment of sewage and industrial effluents. There exist a variety of designs of the activated sludge system, which have been modified from the original design to improve its treatment efficiency and to suit different treatment objectives. In principle the activated sludge system consists of four major components, namely, an aeration tank, supplied with dissolved oxygen, which serves as the bioreactor where the microorganisms (activated sludge) biodegrade the organic matter present in dissolved and colloidal form; a settling tank (or secondary clarifier) which acts as solids liquid separator, separating the activated sludge from the treated sewage effluent; a return sludge pump to return the settled activated sludge (the clarifier underflow) to the aeration tank; and a waste sludge pump to bleed off a portion of the settled activated sludge periodically from the system. This chapter is dedicated to the discussion of the performance monitoring procedure for the following versions of the activated sludge system:

- Conventional activated sludge (CAS)
- Extended aeration activated sludge (EAAS)
- Oxidation ditch (OD)
- Membrane bioreactor (MBR)
- Moving bed biofilm reactor (MBBR)

The first two in the above list are the most widely implemented variants of the activated sludge system in Malaysia. The performance monitoring procedure for the sequencing batch reactor (SBR) systems will also be discussed.

Other activated sludge modifications such as step feed (step aeration), tapered aeration, contact stabilization, and pure oxygen activated sludge systems are not covered in detail this Guidance Document because of their limited application in Malaysia.

10.1 General performance monitoring parameters of activated sludge process

There are three groups of performance monitoring parameters, which are relevant to the operation of the activated sludge systems. These are namely:

- Parameters that describe the environmental conditions prevailing in the bioreactor (i.e. the aeration tank) which the microorganisms are exposed to
- Parameters that indicate the general health status of the microorganisms residing in the bioreactor
- Parameters that signify the treatment efficiency of the activated sludge process

The environmental conditions in the bioreactor are described by parameters such as temperature, dissolved oxygen, pH, and nutrients. The general health status of the microbial population in the bioreactor is characterized by parameters like mixed liquor volatile suspended solids (MLVSS), food to microorganisms (F/M) ratio, sludge age, oxygen uptake rate (OUR), sludge volume index (SVI), and results of microorganism population examination. Efficiency parameters include biochemical oxygen demand (BOD), chemical oxygen demand (COD) and nutrients (nitrogen and phosphorus). These parameters are routinely analyzed by the BP practitioners, to obtain information for monitoring, operating, and maintaining biological treatment processes, especially the activated sludge processes. The following paragraphs briefly review some of the above parameters, which are also for the most part, relevant to other biological treatment processes (BPs).

10.2 Dissolved Oxygen (DO)

10.2.1 DO required for carbonaceous organic removal and nitrification

Sewage is typically treated using aerobic biological treatment systems which require adequate amount of dissolved molecular oxygen (DO) for growth and metabolism of aerobic microorganisms. The oxygen supplied must be able to meet both the demand for the biodegradation of carbonaceous organic matter and nitrification of ammonia. Typically, a DO concentration of 2.5 to 3.5 mg/L is maintained in the aerobic bioreactor, such as the oxidation tank of the activated sludge system. Lack of DO in the bioreactors will promote the growth of filamentous organisms, which may lead to settleability problems in the secondary clarifiers and result in solids washout.

10.2.2 DO in nitrification process

The nitrates formed in the nitrification process need to be removed from the aqueous phase to comply with the sewage discharge standards. Anaerobic facultative bacteria are employed for this purpose in the anoxic system where denitrification process requires an absence of DO or a very low DO level of < 0.2 mg/L.

10.2.3 DO monitoring

DO should be measured at several points in the aeration tank. In large systems, DO should be measured continuously by on-line DO probes and transmitters equipped with a recording device. In smaller systems, DO can be measured by using a portable hand-held DO meter.

Table 10.1 summarizes the dissolved oxygen levels that need to be maintained in the reactors for different aerobic processes.

Table10.1: DO level to be maintained for different processes associated with activated sludge systems

Process	DO, mg/L
Aerobic: carbonaceous removal	1.5 (minimum) to 2.0
Nitrification	2.5 to 3.5
Denitrification	< 0.2 mg/L or zero

10.3 pH

10.3.1 pH for carbonaceous organic removal (aerobic biodegradation)

The aerobic microorganisms require an optimum pH range of 6.5 to 8.5 for performing microbial degradation of the organic matter. Gradual fluctuations within this range may not be detrimental to the process. Low pH conditions encourage the growth of filamentous organisms, which can cause sludge settleability problems in the secondary clarifiers.

10.3.2 pH for nitrification and denitrification processes

The nitrifiers, responsible for the nitrification process, which can occur in an extended aeration activated sludge systems, prefer a pH range of 8.0 to 9.0. However, the denitrifiers, responsible for the denitrification process, which happens in an anoxic tank, prefer a pH range of 7.0 to 7.5.

10.3.3 pH monitoring

For an aerobic process such as an activated sludge system, pH must be monitored, preferably on a continuous basis, at a minimum at one location at the influent end of the aeration tank. If an ASTS is designed for complete nitrogen removal, another pH meter must be installed to monitor the pH in the anoxic tank.

Table 10.2 summarizes the pH levels that need to be maintained in the reactors for different aerobic processes.

Table 10.2: pH value to be maintained for different processes associated with activated sludge systems

Process	pH value
Aerobic: carbonaceous removal	6.5 to 8.5
Nitrification	8.0 to 9.0
Denitrification	7.0 to 7.5

10.4 Mixed liquor suspended Solids (MLSS) and mixed liquor volatile suspended solids (MLVSS)

Solids analysis is a routine task performed in the operation of activated sludge systems. Information on solids is used in the calculation of food to microorganism ratio (F/M ratio), sludge volume index (SVI), recirculation ratio (R), wasting rate (Q_W), etc. In a long and narrow tank such as the plug flow reactor (CAS), samples for MLSS and MLVSS measurements should be taken from three points, namely close to the inlet (i.e. influent end) to the tank, in the middle and at the outlet (i.e. effluent end) of the tank. To compute the sludge age in sequencing batch reactors (SBRs), MLSS sampling for must be performed during reaction and idle stages of its operation cycle.

The MLSS and MLVSS are commonly used to represent the microorganisms in biological treatment processes, especially the activated sludge process. MLVSS is the volatile fraction of the MLSS.

Typical MLSS concentration is maintained within the range of 1,500 to 3,000 mg/L for a conventional activated sludge (CAS) process and 3,000 to 6,000 mg /L for an extended aeration activated sludge (EAAS) process respectively. Membrane bioreactors (MBRs) employ a combination of the activated sludge process (i.e. a suspended growth process) and the membrane filtration system to replace the secondary clarifier. MBBR systems can support a higher MLSS concentration up to 20,000 mg/L.

Table 10.3 summarizes typical MLSS levels that are maintained in the reactors for different BP systems.

Table 10.3: MLSS level to be maintained for different BP systems

BP system	**MLSS, mg/L**
Conventional activated sludge	1,500 to 3,000
Extended aeration activated sludge (including oxidation ditch)	3,000 to 6,000
Membrane bioreactor	10,000 to 20,000

10.5 Sludge volume index (SVI)

The sludge settleability characteristics can be measured by performing the 30 minutes settling test on a mixed liquor sample and from which the sludge volume index (SVI) can be computed. SVI indicates the settling behavior of the sludge in the secondary clarifier. High SVI values imply poor sludge settling which can be the result of predominance of filamentous growth, which could lead to sludge bulking and loss of solids in the clarifier effluent. Other effects of poor settling sludge include low concentration of solids in the return-activated sludge (RAS), which may result in the increase of F/M ratio in the aeration tank. As a consequence, BOD and COD removal efficiency may be reduced.

SVI information is also used to establish the proper recirculation ratio for optimum process efficiency and maximum solids concentration in the waste sludge.

SVI can be computed using the following formula:

$$SVI = \frac{SV_{30} \times 1{,}000}{MLSS}$$

Where :

SVI = sludge volume index, mL/g

SV_{30} = settled sludge volume in 30 minutes, mL/L

MLSS = mixed liquor suspended solids, mg/L

(Note: 1,000 is the conversion factor from mg to g and has the units mg/g))

SVI should be measured routinely to monitor sludge settleability. A as a guide, typical SVI values indicating the settling characteristics of the sludge are given in Table 10.4 below.

Table 10.4: SVI values and sludge settling characteristics

SVI , mL/g	**Sludge settling characteristics**
<50	Excellent
50-100	Good
100-150	Satisfactory
>150	poor-bulking of sludge

10.6 Nutrients

The primary nutrients, which are required by the microorganisms, are nitrogen (N) and phosphorus (P). Other nutrients include iron and trace metals. For aerobic processes such as those occurring activated sludge systems, the recommended minimum weight ratio of BOD_5: N: P: Fe to be maintained in the influent to the aeration tank, should be approximately 100BOD: 5N: 1P: 0.5Fe. Calculation of nutrient availability and dosage required is based only on total inorganic nitrogen (TIN = ammonia + nitrite + nitrate) and ortho-phosphorus. A practical method of checking for nutrient deficiency is to assure that at least 1.0 mg/L IN and 0.5 to 1.0 mg/L ortho-phosphate remains in the aeration tank effluent at all times. Lack of nutrients affects the microbiological processes and promotes filamentous growth resulting in sludge bulking in activated sludge systems.

The nutrient requirements are summarized in Table 10.5.

Table 10.5: Nutrient ratios for aerobic activated sludge process

BP system	**Nutrient ratio required in tank influent**	**Residual nutrient in tank effluent, mg/L**
Activated sludge	100BOD: 5N: 1P	TIN > 1.0; Ortho-P: 0.5 to 1.0 mg/L

10.7 Oxygen Uptake Rate (OUR)

Oxygen uptake rate is a respirometric measurement of the amount of oxygen utilized by microorganisms. OUR is an indicator of the biological activity occurring in the aeration tank, hence the rate of biodegradation of the sewage effluent. Specific oxygen uptake rate (SOUR) is the OUR which has been normalized by the amount of microorganisms present in the sewage sample. A sudden rise in SOUR indicates an upsurge of organic load while a sudden decrease indicates a toxic or pH shock. SOUR is a useful parameter, which should be measured routinely to monitor the biological activity in the aerobic reactor. SOUR, which is also referred to as the respiration rate (RR), can be computed from OUR by the following relationship:

$$SOUR = \frac{OUR}{MLVSS}$$

Where:

SOUR = specific oxygen uptake rate, mg of O_2 /(L h) per g of MLVSS

OUR = oxygen uptake rate, mg of O_2/L per h

MLVSS = X_V = mixed liquor volatile suspended solids, mg/L

Presently, a real time respirometer is available in the market where oxygen utilization studies can be performed using the mixed liquor which is channeled to the respirometer, providing real time OUR data. This is extremely useful for monitoring and controlling the activated sludge systems on a real time basis.

Table 10.6 summarizes typical SOUR values and the corresponding floc settling characteristics.

Table 10.6: Typical range of SOUR values and corresponding floc and settling properties.

SOUR, mg O_2/h g MLVSS	Floc description	Settling characteristics
> 20	Dispersed floc	Settling Slow
8-20	Flocs forming	Settling normal
< 8	Pin Floc	Settling too fast

10.8 Food to microorganism (F/M) Ratio

Food to microorganism (F/M) ratio expresses the amount of substrate (food) available to the microorganisms in the aeration tank. Insufficient amount of food or overdose of it will lead to settling problems in the clarifier and poor organics removal efficiency. The amount of food is represented by the BOD of the sewage influent, while the amount of microorganisms is represented by the MLVSS. F/M ratio should be determined on a routine basis for monitoring the activated sludge process.

F/M ratio is calculated by using the following formula:

$$F/M = \frac{BOD_{in}\ (Q)}{V_r\ (X_V)}$$

Where:

F/M = food to microorganism ratio, $\frac{\text{kg BOD per d}}{\text{kg MLVSS under aeration}}$

BOD = biochemical oxygen demand of influent to the aeration tank, mg/L

Q = influent flowrate, m^3/d

V_r = aeration tank volume, m^3

X_V = MLVSS = mixed liquor volatile suspended solids, mg/L

For the computation of F/M ratio, BOD can be computed form COD, if a BOD COD correlation ratio has been established for the sewage influent.

Typical F/M ratios for different activated sludge system are given in Table 10.7.

Table 10.7: Typical F/M ratios for different types of activated sludge system

Type of activated sludge process	F/M ratio, $\frac{\text{kg BOD per d}}{\text{kg MLVSS}}$
CAS	0.2 to 0.5
EEAS	0.05 to 0.15
Oxidation ditch	0.05 to 0.15

10.9 Sludge age

Sludge age (θ_c) measures the average time in days, the microorganisms remain the aeration tank before they exit. θ_c is a design and an operational parameter, which is calculated using the following formula:

$$\theta_c = \frac{V_r(X)}{Q_W(X_W)}$$

Where:

θ_c = sludge age, d

V_r = aeration tank volume, m^3

X = MLSS= mixed liquor suspended solids concentration, mg/L

Q_W = sludge wasting rate, m^3/d

X_W = wasted sludge suspended solids concentration, mg/L

(Note: The above equation neglects the solids leaving through the clarifier weir)

For sequencing batch reactor (SBR) systems, the sludge age formula is modified as follow:

$$\theta_c = \frac{V_r(X)\,t_c}{Q_W(X_W)\,24}$$

Where:

t_c = total cycle time, h

Typical sludge age ranges for different processes are given in Table 10.8.

Table 10.8: Typical sludge age range for different processes associated with activated sludge systems

Type of process	Sludge age, d
CAS	5 to 10
EAAS	12 to 30
Nitrification	20 to 40
Denitrification	2 to 3

10.10 Oxygen reduction potential (ORP)

Oxidation reduction potential (ORP) value of a solution indicates whether the solution is in an oxidizing or reducing enviroment. In the activated sludge systems, typical processes which are occuring in the bioreactors are biodegradation of carbonaceous organic matter (C-BOD), nitrification (NH_3 to NO_2^- and NO_3^-), biological phosphorus removal, and denitrification (NO_3^- to N_2). All the above processes are aerobic in nature with the exception of denitrification, which is an anoxic process. Each of the above processes occurs within its own range of ORP values which are summarized in Table 10.9. Oxidation-reduction (ORP) measurements can easily be made using a Redox meter.

Table 10.9: Biochemical reactions in treatment processes associated with activated sludge systems and their ORP ranges

Biochemical reactions	**ORP, mV**
C-BOD	+ 50 to + 250
Nitrification	+ 100 to + 350
Denitrification	+ 50 to - 50
Biological phosphorus removal	+ 25 to + 50
Acidogenesis	- 40 to - 250
Acidogenesis	- 175 to - 400

10.11 Hydraulic loading

Hydraulic loading is the amount of flow entering the treatment system. The activated sludge system has been designed to process a certain flowrate of sewage and all the treatment components have been sized based on the flowrate. Hydraulic overloading and underloading must be avoided in order to maintain the efficiency of the activated sludge system. Hydraulic overloading affects the system more than underloading. Overloading may lead to loss of solids through the secondary clarifier resulting in dilute return sludge concentration and deterioration of treated effluent quality.

10.12 Microscopic examination

There are different groups of microorganisms residing in the biological treatment systems such as the ponding system, the suspended growth system (activated sludge process), or the attached growth system (trickling filters and rotating biological contactors). Because each of these groups thrives best under certain conditions, their presence or absence can be related to the degree of treatment, hence the efficiency of the treatment system utilizing biological processes.

In activated sludge systems, the bacteria are responsible for stabilization of most of the organic matter contained in the effluent and also for floc formation which helps in sludge settling. Protozoa can be used as an indicator of the efficiency the treatment process. Although protozoa themselves do not stabilize the organic matter in the effluent, they feed on the dispersed bacteria and this helps clarify the effluent. The presence of ciliated protozoa in a biological treatment process such as an activated sludge process is indicative of an efficient treatment process. The presence of rotifers, a metazoan, is indicative of a condition of very low F/M ratio or high sludge age (old sludge).

Filamentous organisms when present in abundance in an activated sludge can result in sludge bulking which may lead to sludge carryover in the clarifier effluent and discharge noncompliance. The factors that foster the growth of filamentous organisms include low pH, low DO, low nutrient levels, septicity, high oil and grease, and high sulfide.

It is recommended that weekly or preferably, daily microscopic examinations of the microorganisms in the mixed liquor sample from the biological reactor (such as the aeration tank of an activated sludge system) are performed to observe:

- The bacterial floc size and shape
- The presence of filamentous bacteria
- The changes in the number of protozoans (flagellates, ciliates)
- The presence of rotifers

Typically, a microscope with a magnification power of 100 x to 200 x is adequate for the above purpose.

The above discussion is most relevant to a suspended growth system such as the activated sludge system. However, for the most part, the discussion is also applicable to other biological treatment systems such as the lagoon systems, trickling filters and rotating biological contactors.

10.13 Conventional plug flow and complete mix activated sludge systems

A schematic diagram of the activated sludge system is shown in Fig. 10.1. From physical characteristics perspective, the conventional activated sludge system is characterized by introduction of sewage influent and return activated sludge (RAS) at one end of the aeration tank, a plug flow aeration tank, and diffused aeration. The complete mix activated sludge is characterized by introduction of sewage influent and return activated sludge throughout the aeration basin and the use of a completely mixed aeration tank. Complete mix aeration tanks may be arranged in series to approximate plug flow and conventional activated sludge system.

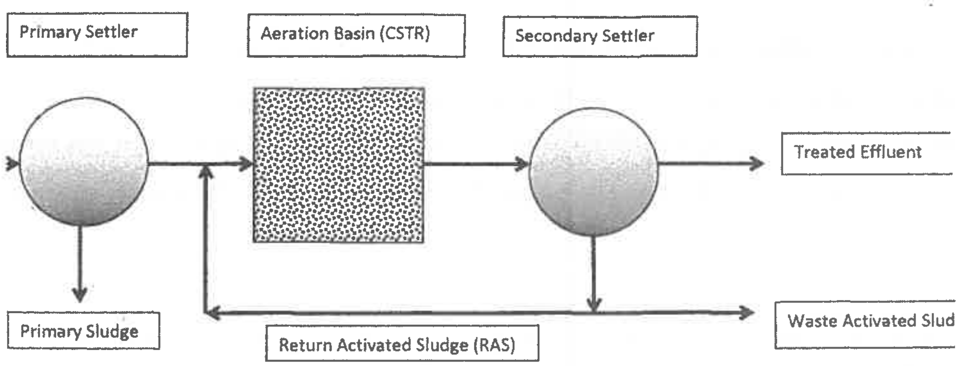

Fig. 10.1: A general schematic diagram of the activated sludge system

10.13.1 Design and operating criteria

The major differences between the CAS and EAAS are as follows. The EAAS operates at a higher MLSS concentration, hydraulic retention time (aeration time), and sludge age than the CAS. On the other hand, the F/M ratio of the EAAS is lower than that of the CAS. Both versions of the activated sludge system are capable of achieving high degree of removal of BOD and SS. Nitrification can also be accomplished when the system is designed to operate at high sludge ages. The design and operating criteria for the CAS and EAAS systems are summarized in Table 10.10.

Table 10.10: Typical design and operational criteria for conventional and extended aeration activated sludge systems (Source: adapted from Spellman, 2014)

Parameter	CAS	EAAS
Hydraulic retention time, h	4 to 8	24
Settling time, h	2 to 4	2 to 4
Return rate (%)	25 to 100	25 to 100
MLSS, mg/L	1,500 to 3,000	4,000 to 6,000
DO, mg/L	2.5 to 3.5	2.5 to 3.5
F/M, kg BOD/(kg MLVSS.d)	0.2 to 0.5	0.05 to 0.15
Sludge age, d	5 to 10	12 to 30
Primary treatment	Yes	No

10.13.2 Treatment performance

Conventional and extended aeration activated sludge systems can achieve a BOD and TSS removal of 85 to 90 %.

10.14 Oxidation ditch

An oxidation ditch is a modified version of the activated sludge which is constructed in a ring or oval shape configuration, equipped with aeration devices such a brush rotor, disc aerators, draft tube aerators, or fine bubble diffusers. Oxidation ditches are typically complete mix systems operated in an extended aeration mode at high sludge ages to remove biodegradable organics. Additionally, the ditch can be designed to also remove nitrogen. The solids are maintained in suspension as the mixed liquor circulates around the ditch. The secondary clarifier, which settles the oxidation ditch effluent, provides the concentrated sludge for sludge return and sludge wasting. Fig. 10.2 shows a schematic diagram of an oxidation ditch.

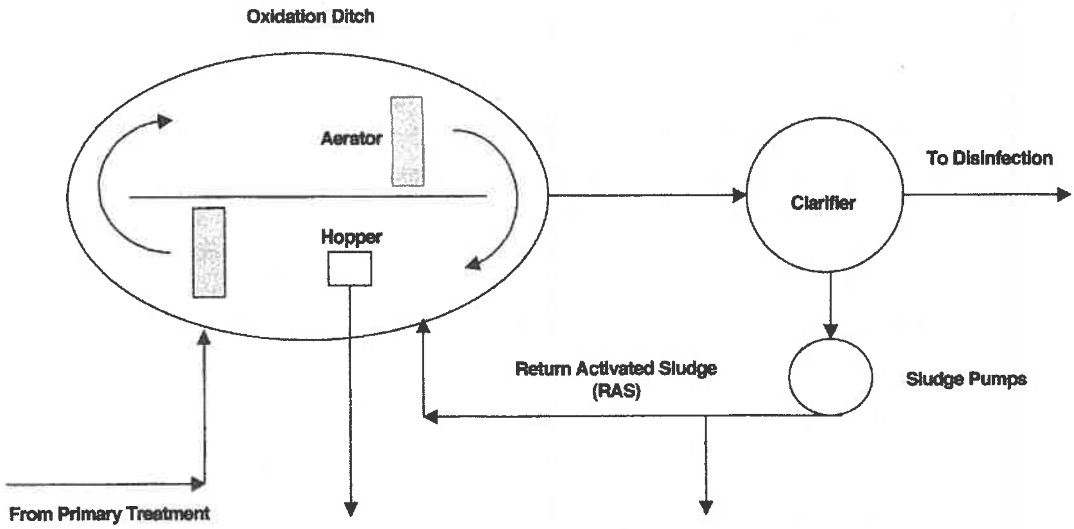

Fig. 10.2: A schematic diagram of an oxidation ditch (USEPA, 2000)

10.14.1 Design and operational criteria

Oxidation ditches are typically designed and operated as an extended aeration activated sludge. The sludge age selected is dependent on the effluent quality requirements. To accomplish nitrification, typical sludge age ranges from 12 to 30 days. A BOD loading rate of 240 g/1,000 L is commonly used as a design loading rate.

10.14.2 Oxidation ditch performance

Oxidation ditches can achieve greater than 90% removal of BOD, TSS, and ammonia.

10.15 Step aeration or step feed activated sludge

Step aeration activated sludge is characterized by introduction of primary settled sewage at two or more points in the aeration tank, use of a plug-flow aeration tank, and diffused aeration. This results in reducing the oxygen demand at the influent end of the tank.

10.16 Tapered aeration

Tapered aeration is similar to conventional activated sludge except that the air supply is tapered to meet the organic load within the tank. More air spargers are installed at the influent end of the tank to provide more aeration where the organic loading and oxygen demand are the greatest.

10.17 Contact stabilization

Contact stabilization activated sludge is characterized by the use of two aeration tanks for each process train, one to contact the sewage influent and return activated sludge (contact tank) and the other to aerate the return activated sludge (stabilization tank) and promote the biodegradation of the organics absorbed to the bacterial flocs.

10.18 Performance monitoring procedure for activated sludge systems

Activated sludge treatment systems (ASTSs) are comparatively more complex than the ponding systems or the attached growth systems. The operation of ASTSs requires constant attention from dedicated, trained personnel. The systems are more demanding in their requirements for continuous and close monitoring of the processes (performance monitoring). The performance monitoring (PM) of the ASTSs involves scheduled effluent sampling and analysis, measurements of PM parameters (i.e. the three groups as discussed earlier), making observations (general and specific) of the conditions within the ASTS components, performing ASTS calculations, and making pertinent conclusions on the status of the ASTS performance. The conclusions are then translated into response actions and operational changes required to maintain and operate the ASTS in an optimal manner, to produce quality effluent on a consistent basis.

The parameters, effluent sampling stations and monitoring frequency for performance monitoring of activated sludge systems are summarized in Table 10.11.

Table 10.11: Recommended sampling requirements for an activated sludge system

Parameter	Sampling location Description	Sample type	Sampling frequency
Aeration tank			
DO	In the aeration tank, preferably at three locations	In-situ	Daily
MLSS*	In the aeration tank	Grab	Daily
MLVSS (from MLSS analysis)	-	-	Weekly
SVI	Aeration tank outlet or	Grab	Daily

	close to outlet**		
pH	In the aeration tank	In situ	Daily
ORP	In the aeration tank	In situ	Daily
SS of RAS	RAS line	Grab	Daily
SS of WAS	WAS line	Grab	Daily
Q_{RAS}	RAS line	Totalizer	Daily
Q_{WAS}	WAS line	Totalizer	Daily
F/M ratio **	-	-	Weekly
SOUR	In the aeration tank at the effluent end	Grab	Weekly
Microscopic examination	In the aeration tank	Grab	Weekly

10.19 Membrane bioreactors (MBRs)

A membrane bioreactor (MBR) is a combination of the activated sludge process (suspended growth) and a membrane filtration system. The latter replaces the secondary conventional gravity clarifier and sand filters in a typical activated sludge treatment system. Sometimes chemical addition is included if phosphorus removal is an additional objective of treatment. Equalization (external or internal) may be provided in the design to handle high flows. To prevent damage to membranes, fine screens may be installed after the primary clarifier and/or before the membranes. Membrane filtration unit may be immersed in the aeration tank (submerged, internal design) or placed in a separate external vessel (external design). Membranes are of two configurations: hollow fiber bundles or flat plate frame membranes. Each configuration requires different screening requirement. Both the internal and external membrane designs require some degree of pumping to force the effluent through the membranes. Schematic diagrams of an MBR are shown in Fig. 10.3 (internal design) and Fig. 10.4 (external design).

10.19.1 Performance monitoring requirements

Since the MBR system is principally an activated sludge treatment system (ASTS), the performance monitoring requirements are for the most part similar to those of the ASTS. The additional PM requirements are associated with the monitoring of the filtration unit. These include ensuring effective screening of large solids, throughput rates, and regular membrane cleaning. Cleaning is typically accomplished by using sodium hypochlorite and citric acid. Table 10.12 summarizes the typical PM parameters, the sampling locations and the sampling frequency for monitoring the performance of the membrane bioreactors (MBR).

10.19.2 Performance of MBR

MBR systems outperform the conventional activated sludge systems. The use of membrane filtration permits a high concentration of microorganisms (MLSS) to be maintained in the system and a high sludge age. As a result a smaller system footprint is achieved. MBR produces high quality effluent, which contains low concentrations of BOD, COD, TSS, ammonia and phosphorus. If operated with high sludge ages, MBR systems generate low sludge production.

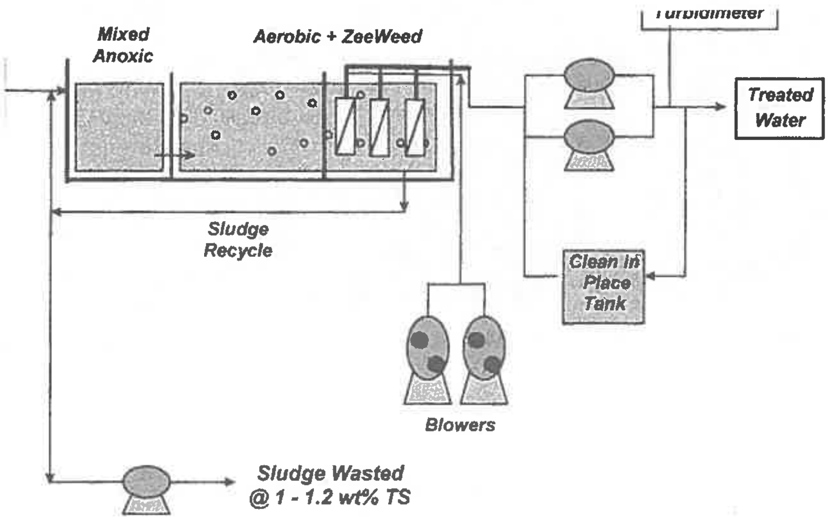

Fig. 10.3: A schematic diagram of a membrane bioreactor (internal membrane unit) (USEPA, 2007)

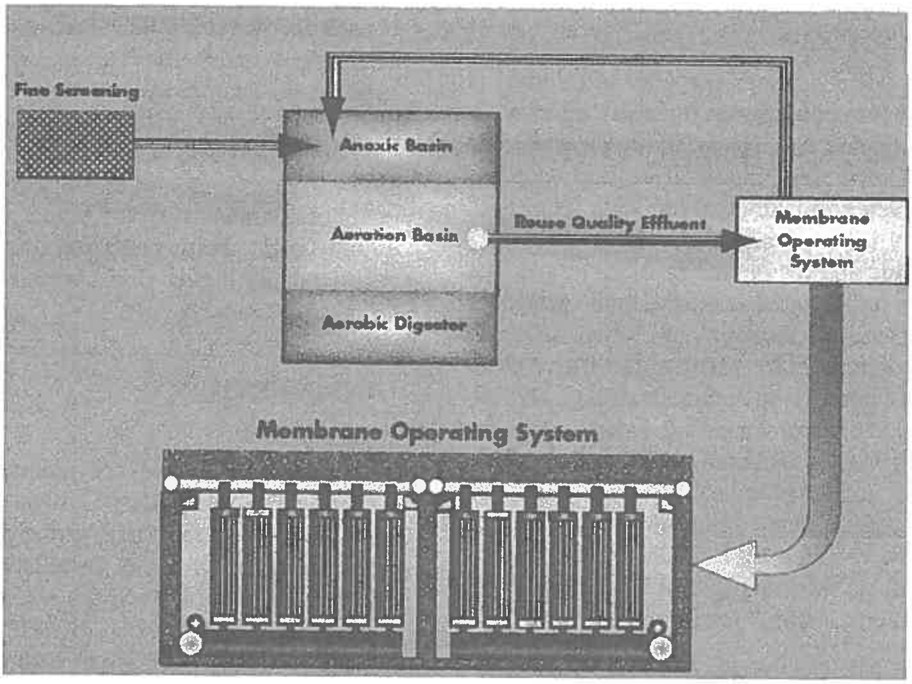

Fig. 10.4: A schematic diagram of a membrane bioreactor (external membrane unit) (USEPA, 2007)

Table 10.12: Recommended performance monitoring specifications for membrane bioreactor (MBR) systems

Parameter	Monitoring Frequency	Sampling Location
Permeate flux	Continuous	MBR
HRT	Daily calculation (less frequent, if flow variation is low)	Influent
Sludge age	Daily calculation	Reactor
F/M	Daily calculation	Reactor
Transmembrane pressure (TMP)	continuous	Reactor
MLSS, MLVSS	Daily or weekly	Reactor
Temperature	Continuous	Influent and MBR tanks
Flow	Continuous	Influent
Dissolved Oxygen	Continuous	EQ and Reactor
COD (or alternatively BOD)	Continuous (for large systems) or weekly if variation is low	Influent & Permeate
Microbiology	Weekly	Reactor

N&P	Monthly (less frequent if variation in influent characteristics is low)	EQ
pH	Continuous	Influent and EQ

10.20 Moving bed biofilm reactors (MBBRs)

Moving bed biofilm bioreactor (MBBR) is a combination of activated sludge process (suspended growth) and biofilter (attached growth). MBBR system utilizes the whole tank volume for biomass growth. Floating media are used as carriers for the growth of biofilms. Various carrier materials have been used in MBBR systems but nowadays, carriers are typically made of polyethelene. Air diffusers installed at the bottom of the tank provide the agitation of air bubbles to maintain the biofilm carriers in motion. The environment in the tank promotes the growth of aerobic "BOD bacteria" which remove the organic matter and nitrifiers, which convert ammonia to nitrates. The HRT of the reactor ranges from 3 to 5 hours. Pretreatment processes such as primary sedimentation, coagulation, screening, and secondary clarification may be used in combination with the MBBR system. Common design of MBBR is typically based on organic load/(m^2 .d), with no sludge recycling and F/M is not a design parameter. Fig. 10.5A shows a schematic diagram of a MBBR and Fig. 10.5B shows a photo of the biofilm carriers. Fig. 10.6 shows a photo of a type of plastic carrier which is commonly used in MBBR systems.

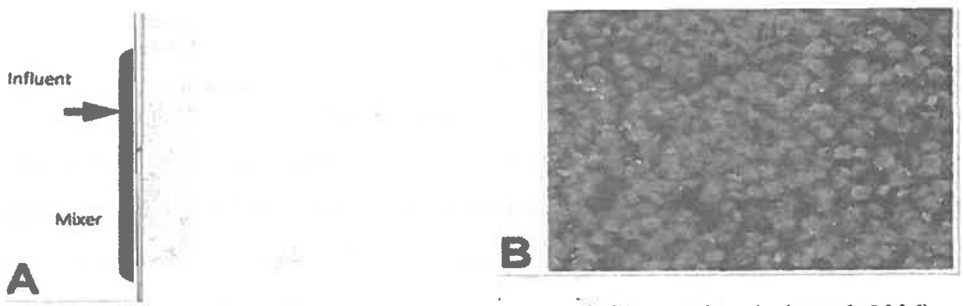

Fig 10. 5: A: MBBR schematic diagram B: Biofilm carriers (Ødegard, 2006)

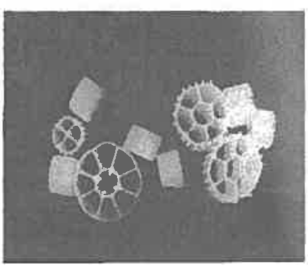

Fig. 10.6: Plastic carriers used in MBBRs (Neethling, 2010)

10.20.1 Performance monitoring of MBBR

The performance monitoring requirements as described for the activated sludge system are also generally applicable to the MBBRs. However, some parameters such as RAS and F/M are not relevant. The recommended PM sampling requirements are summarized in Table 10.13.

Table 10.13: Recommended sampling requirement for monitoring MBBR systems

Parameter	Frequency
Influent COD to MBBR tank	Twice weekly
Nutrient (Total N and P) in influent to MBBR	Fortnightly
Influent flow rate to MBBR tank	Continuous
DO in MBBR tank	Continuous
MLSS in MBBR tank	Twice a week
SV_{30} test	Daily
F/M Ratio	Weekly
Sludge floc microscopy	Weekly

10.20.2 Performance of MBBR

MBBR can achieve BOD removal of 90 to 95% and nitrogen removal of about 85%.

10.21 Sequencing batch reactors (SBR)

The SBR process is a fill-and-draw, non-steady state activated sludge process in which one or more reactor basins are filled with wastewater during a discrete time period, and then operated in a batch treatment mode. SBRs accomplish equalization, aeration, and clarification in a timed sequence. Fig 10.7 shows a flow diagram of a sewage treatment system that incorporates a SBR in its treatment train.

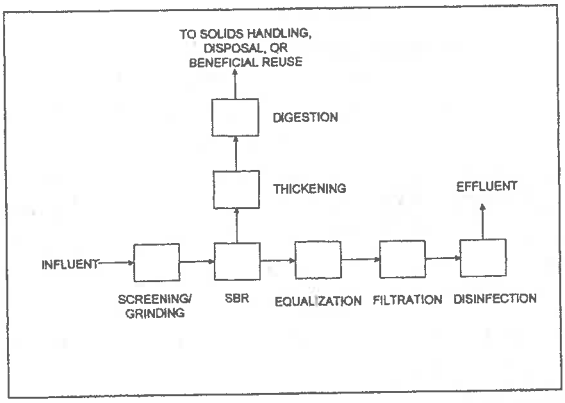

Fig. 10.7: An STS treatment train incorporating an SBR

10.21.1 Design and operating criteria

The unit processes of the SBR are similar to those of activated sludge systems. Typical design and operating criteria are summarized in Table 10.14.

Table 10.14: Key design and operating parameters for SBR (USEPA, 1999)

Parameter	**Value**
Food to microorganism (F/M)	0.15 kg BOD to 0.4 kg/(kg MLVSS.d)
Treatment cycle	4.0 h
Low water MLSS	2,000 to 4,000 mg/L
HRT	16 to 14

(for conventional load)

As shown in Fig. 10.8, the operation of SBRs consists of five basic steps: Fill, react, settle, draw, and idle. Treated effluent is discharged during the draw (or decant) stage while sludge wasting is typically performed during the idle stage.

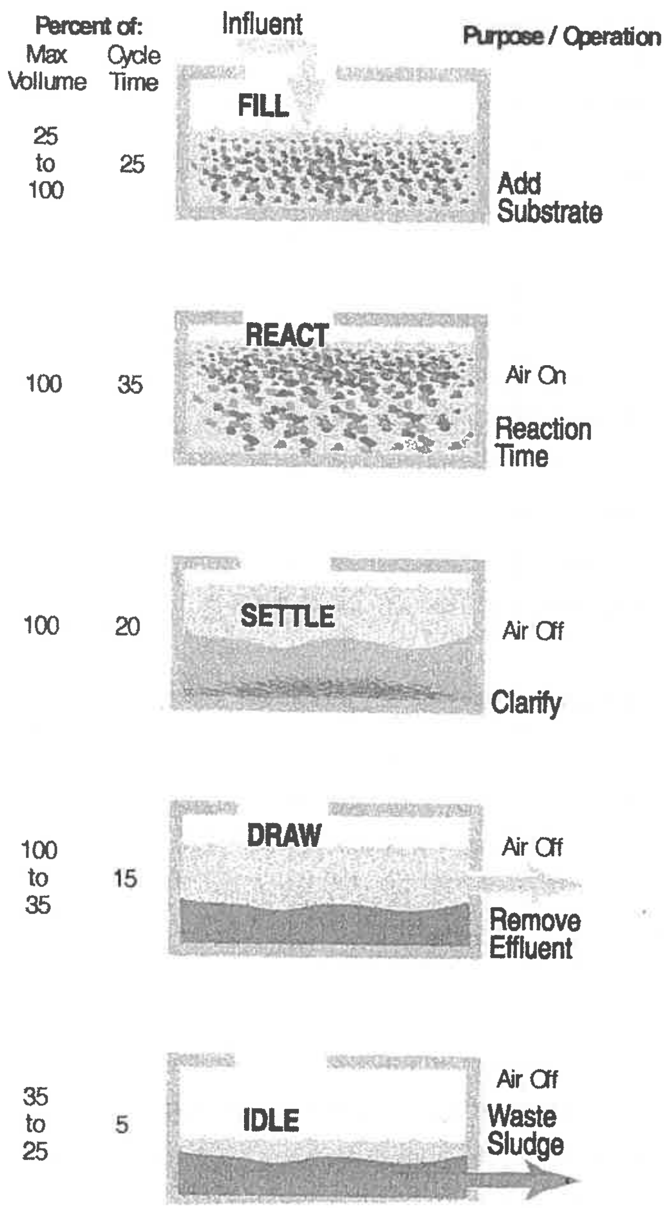

Fig. 10.8: Typical SBR operating cycle (NSF, 2003)

10.21.2 Performance monitoring

Performance monitoring procedure for SBR systems includes the monitoring of the following parameters, which are similar to the activated sludge systems: DO, ORP, ammonia nitrogen, nitrite, nitrate nitrogen, MLSS, MLVSS, sludge age, F/M ratio, SV_{30}, SVI, alkalinity, pH, temperature, and microscopic examination. (Note:

alkalinity should not fall < 50 mg/L in the SBR for nitrifying systems and should be about 100 mg/L in the effluent after complete nitrification)

10.21.3 Treatment performance of SBR

SBRs can achieve a BOD removal efficiency of 85 to 90%, producing treated sewage effluent quality of BOD < 10 mg/L, TSS < 10 mg/L, TN, between 5 to 8 mg/L, and TP between1 to 2 mg/L.

10.22 Secondary clarifiers

The purpose secondary clarification is to separate the biological solids from the mixed liquor and produce a clear supernatant, low in suspended solids and BOD, hence the treated effluent is fit for discharge. Although secondary clarifiers come under the category of a physical chemical process (PCP), their presence in an activated sludge system is required to complete the activated sludge treatment train. The secondary clarifier is an integral part of any version of the activated sludge treatment system hence its discussion is included in this chapter.

10.22.1 Design and operational criteria

The following are general criteria which are commonly used in the design and operation of secondary clarifiers.

10.22.1.1 Detention time

Detention time (DT) is an expression of hydraulic loading, indicating how long the bioreactor effluent will take to pass from the clarifier inlet to the outlet. This is typically expressed in hours.

The formula for calculating DT is:

$$DT = \frac{V}{Q}$$

Where:

DT = clarifier detention time, h

V = clarifer volume, m^3

Q = bioreactor effluent flow rate, m^3/h

Typical design and operating DT for secondary clarifiers usually ranges between 2 and 3 hours.

10.22.1.2 Surface overflow rate

Surface overflow rate (SOR) is another expression of hydraulic loading which expresses the amount of sewage being admitted into the cross sectional area of the clarifer.

The formula for calculating SOR is:

$$SOR = \frac{Q}{A}$$

Where:

SOR = surface overflow rate, $m^3/(m^2 .d)$

Q = sewage influent fow rate, m^3/d

A = surface area of clarifer volume, m^2

The recommended SOR range depends on the ASTS type. For CAS, typical range is from 16 to 31 $m^3/(m^2.d)$ at Q_{avg} and 40 to 64 $m^3/(m^2.d)$ at Q_{max} respectively. For EAAS, the values are 7 to 16 and 24 to 31 $m^3/(m^2.d)$, respectively.

10.22.1.3 Weir overflow rate

Weir overflow rate (WOR) is also often used to express hydraulic loading. WOR is the amount of sewage flowing over the length of the weir.

The formula for calculating WOR is:

$$WOR = \frac{Q}{L_w}$$

Where:

WOR = weir overflow rate, $m^3/(m .d)$

Q = sewage influent fow rate, m^3/d

L_w = weir length, m

Typical range for WOR is from 100 to 300 $(m^3/(m.d)$ at Q_{avg} and at Q_{max} respectively.

10.22.1.4 Solids loading rate

Solids loading rate (SLR) relates to the weight of solids entering the clarifier surface area.

The formula for calculating SLR is:

$$SLR = \frac{QX}{A}$$

Where:

SLR = solids loading rate, kg/(m^2 .d)

Q = total sewage influent flow rate to the clarifier, m^3/d

X = concentration of suspended solids, mg/L

A = surface area of clarifier, m^2

(Note: Q = PE + RAS: PE is settled primary effluent; RAS is return activate sludge))

The recommended SLR range depends on the ASTS type. For CAS, typical range is from 96 to 144 kg/(m^2.d) at Q_{avg} and 240 kg/(m^2.d) at Q_{max} respectively. For EAAS, the values are 24 to 120 and 168 kg/(m^2.d), respectively.

10.22.2 Performance monitoring procedure for secondary clarifiers

The performance monitoring requirements for secondary clarifiers are summarized in Table 10.5.

Table 10.5: Performance monitoring requirements for secondary clarifiers

Parameter	Sampling point	Frequency	Notes
Sludge level	Middle of clarifier	Daily or several times daily	-
BOD	Clarifier effluent	Weekly	-
COD	Clarifier effluent	Daily	-
TSS	Clarifier influent and effluent	Daily	To calculate SLR
pH	Clarifier influent and effluent	Daily	A drop in pH indicates septic sludge in the clarifier. Observe for gassing and ashing.
TIN	Clarifier effluent	Monthly	-
Q	Clarifier influent	Daily	To calculate DT, SOR, WOR
DO	Clarifier influent and effluent	Daily	A large drop in DO indicates biological activity still occurs in the clarifier.
Weir cleaning	-	Whenever required	Can be made by using water spraying or

			automatic weir cleaner.
Performing preventive and corrective maintenance of the clarifier weir	-		To keep it in clean and level condition.

The recommended sludge depth to be maintained is not more than a third of clarifier depth. Sludge depth can be measured by using a core sampler, sludge judge, an automatic sludge depth meter or sludge gun. Clarifier monitoring is not relevant to sequencing batch reactors (SBRs) and membrane bioreactors (MBRs).

CHAPTER 11: PERFORMANCE MONITORING OF TERTIARY TREATMENT PROCESSES

CHAPTER 11: PERFORMANCE MONITORING OF TERTIARY TREATMENT PROCESSES

In sewage treatment field, tertiary treatment generally refers to the processes used to further treat the secondary sewage effluent to remove nitrogen and phosphorus. Although the term, advanced treatment, is often used synonymously with tertiary treatment, advanced treatment covers a wider scope of treatment objectives, not only limited to nitrogen and phosphorus removal. These contaminants may include TSS, refractory organics, or metals. This chapter briefly discusses the performance monitoring of treatment processes to remove nitrogen and phosphorus from secondary treated sewage effluents. Nitrogen removal has been mentioned in passing in the earlier chapter on suspended growth systems.

11.1 Removal of nitrogen

Complete removal of nitrogen from sewage is necessary because both forms of nitrogen, i.e. ammonia nitrogen and nitrates are regulated under Sewage Regulations. Complete treatment for ammonia using biological treatment involves a two step process which requires different environmental conditions and different microbial groups. The first steps is nitrification process which is performed by the aerobic nitrifying bacteria, which can thrive in activated sludge systems operated at high sludge ages, such as the extended aeration activated sludge (EEAS) system. The second step requires an environment devoid of oxygen or with a very low oxygen level, which would be conducive to the anaerobic denitrifying bacteria. The second step typically requires a separate reactor, commonly referred to as the anoxic reactor. An external carbon source such as methanol or acetic acid is usually added to the anoxic reactor to provide the carbon required by the denitrifiers. Typical flowcharts of the activated sludge process, which have been modified with different arrangements to achieve nitrification and denitrification of sewage, are shown in Fig. 11.1.

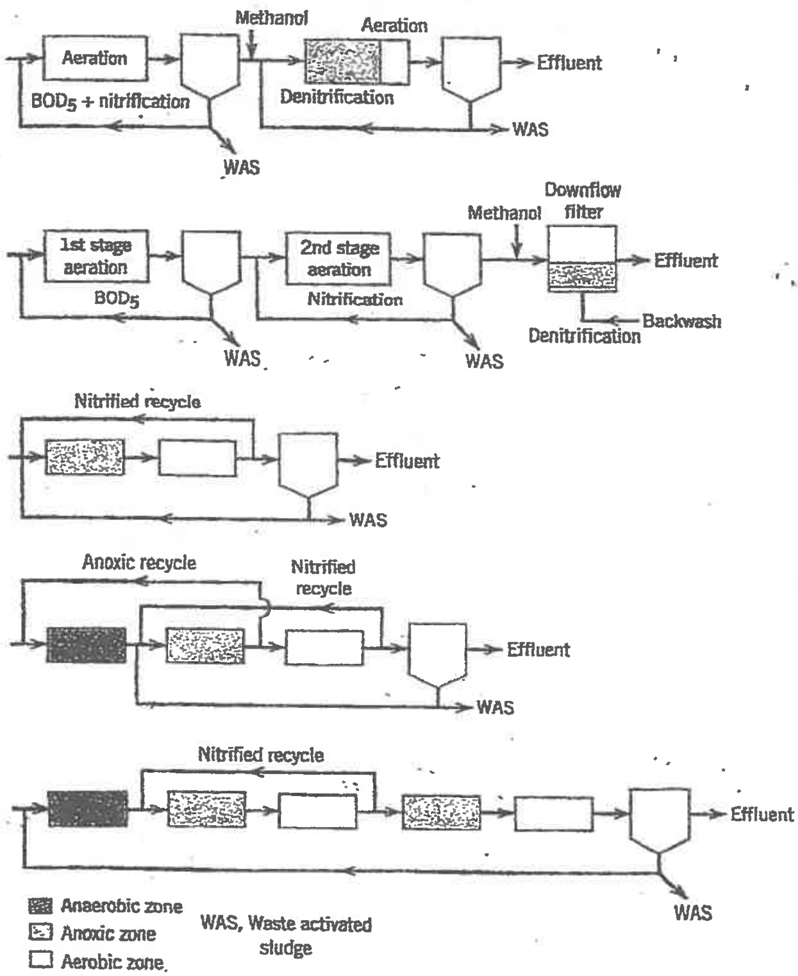

Fig 11.1: Flowcharts of nitrification and denitrification process for sewage treatment (USEPA, 1993)

11.2 Performance monitoring of nitrification and denitrification processes

The conditions to be maintained in both reactors: the ASTS, where the both organic removal and nitrification take place and the anoxic reactor where denitrification takes place are summarized in Table 11.1.

Table 11.1: Recommended performance monitoring parameters and their ranges (Summarized from USEPA, 1993; YSI Environmental)

Process	Parameter				
	DO, mg/L	pH	ORP, mV	θ_c, d	HRT, h
Nitrification	2.5-3.0	8-9	+100 to +350	20 - 40 (minimum: 10)	-
Denitrification	Very low or zero	7.0-7.5	+50 to -50	2-3	1 to1.5

Based on the Table above, for the purpose of performance monitoring, the following parameters are monitored: DO, pH, and ORP. Additional monitoring for the denitrification process is the monitoring of the amount of organic compound used as an external source of carbon, which is added to the anoxic tank. Daily sampling is recommended for all parameters.

CHAPTER 12: PERFORMANCE MONITORING OF DISINFECTION SYSTEMS

CHAPTER 12: PERFORMANCE MONITORING OF DISINFECTION SYSTEMS

Untreated and secondary treated sewage effluents (effluents from biological treatment systems-BPs) contain a myriad of pathogenic microorganisms that pose a potential risk to the health of humans and livestock. The microorganisms include helminths, bacteria, protozoa, and viruses. Various methods have been used for disinfecting treated sewage effluents, which not only meet the main objective of reducing the population of pathogenic microorganisms below the minimum standards but are reliable and cost effective, and do not increase the toxicity of the treated effluent. This chapter discusses briefly the performance monitoring of the most widely used disinfection techniques.

12.1 Chemical disinfection methods

12.1. Chlorination

Chlorination is most widely used technique for disinfecting secondary treated sewage effluents. However, in some countries chlorination is strictly prohibited in designated catchments due to toxicity to sensitive receiving streams posed by chlorine and its byproducts (chloramines). The forms of chlorine used are gaseous chlorine (Cl_2) and hypochlorite salts.

12.1.2 Design and operation criteria

The control of disinfection process is commonly based on maintaining a certain total residual chlorine, for a specific contact time, at design flow. Typically, a design contact time of 30 minutes, the required minimum total residual chlorine concentration is 1.0 mg/L. Some of the calculations involved in the design and operation of chlorination systems are given below:

12.1.2.1 Chlorine demand

Chlorine demand is the difference between the amount of chlorine added (chlorine dose) to the sewage effluent and the chlorine residual required. The chlorine demand represents the chlorine required to complete all reactions before residual can be produced. The chlorine demand is computed by using the formula:

Chlorine demand, mg/L = (Chlorine dose, mg/L) - (Chlorine residual, mg/L)

12.1.2.2 Chlorine feed rate

Chlorine feed rate is the amount of chlorine added to the sewage effluent per day. Chlorine feed rate is calculated by using the formula:

$$\text{Chlorine feed rate, kg/d} = \frac{(\text{Chlorine dose, mg/L})\ (\text{Sewage effluent flowrate, m}^3/\text{d})}{1{,}000}$$

(Note: 1,000 is the final conversion factor to convert mg to kg and L to m^3)

12.1.2.2 Quantity of dry hypochlorite

If the chlorine source used for disinfection is hypochlorite, the following formula is used to calculate the amount of hypochlorite required:

$$\text{Hypochlorite required, kg/d} = \frac{(\text{Required chlorine dose, mg/L})(\text{Sewage flowrate, m}^3/\text{d})}{(\%\ \text{Available chlorine})\ (1{,}000)}$$

(Note: 1,000 is the final conversion factor to convert mg to kg and L to m^3)

12.1.2.3 Performance monitoring of chlorination system

Typical performance monitoring of chlorination systems include the monitoring of bacteria count (fecal coliform) and performing a total chlorine residual test of the final effluent. The operator also monitors and ensures the following by physical observation: the effluent is distributed evenly through the chlorination units and no short circuiting is observed; no solids accumulate in the contact tank; and no sign of chlorine leakage from the chlorinator.

12.2 Ultraviolet irradiation

Ultraviolet irradiation is an attractive disinfection alternative that is gaining popularity worldwide because it offers several advantages such as: it is a physical process rather than a chemical disinfectant; it produces no residual; it is user-friendly; it needs a shorter contact time; and it requires a smaller foot print than other technologies. The stringent control over discharge of toxic chlorine residuals is another impetus for the change from chlorination of sewage effluents to UV irradiation.

12.2.1 Design and operating criteria

UV disinfection is applicable to sewage effluents which has undergone secondary or advanced treatment. Its effectiveness depends on the sewage effluent characteristics, the irradiation time, and the reactor configuration. The most important effluent characteristic that influences the disinfection efficiency is the concentration of colloidal and particulates. An integral part of the UV disinfection system design is the contact tank which should provide a minimum exposure time of 10 seconds.

12.2.2 Operation and maintenance and performance monitoring of UV disinfection systems

Routine monitoring of the UV system includes checking on bulb burnout, solids build up on quartz tubes, and UV light intensity. UV system maintenance includes periodic cleaning of the various components such as the quartz sleeves or Teflon tubes using either mechanical wipers, ultrasonics, or chemicals.

CHAPTER 13:
MONITORING OF FINAL EFFLUENT

CHAPTER 13 -MONITORING OF FINAL EFLUENT

The result of painstaking efforts to implement rigorous performance monitoring plan and hardware maintenance program is reflected in the good quality of treated sewage effluent discharged through the final discharge point (FDP). The discharge of compliant effluent on a continuous basis is a great achievement and a success story of sewage treatment that not only makes the discharger SR compliant, but it brings peace of the mind to the sewage discharger that he has done his duty to minimize the environmental impact posed by his discharge.

13.1 Compliance monitoring

Compliance monitoring refers to the monitoring of treated sewage effluent discharged through the final discharge point (FDP). It is part and parcel of the overall performance monitoring plan of the STS to assess its compliance status with the discharge standards. Compliance monitoring of the treated sewage effluent at the FDP is dictated by regulation 10 of the Sewage Regulations (SR) where the effluent samples are required to be sent for analysis to the accredited laboratory.

13.2 Parameters to be monitored

Generally, regulation 10 of the SR requires the following parameters to be monitored: temperature, pH, BOD, COD, suspended solids, oil and grease, ammoniacal nitrogen, nitrate nitrogen and phosphorus. However, some parameters may not be required depending on the installation date of the STS, the STS type, and the discharge location.

13.3 Monitoring frequency

The frequency of monitoring the final effluent ranges from weekly, for STS with 5000 or more population equivalent to monthly, for others.

CHAPTER 14: SOLIDS HANDLING AND DEWATERING OPERATIONS

CHAPTER 14: SOLIDS HANDLING AND DEWATERING OPERATIONS

In the operation of sewage treatment systems, sludges are produced at two major points in the STS treatment flow scheme. These are the primary clarification and secondary clarification stages. The primary sludge (sometimes referred to as raw sludge) is the materials that have settled on the bottom of the primary clarifier. This sludge is objectionable and contains a high percentage of water. The secondary sludge is principally biological solids (i.e. microorganisms which populate the aeration tank) that have settled on the bottom of the secondary clarifier. These solids are colloidal suspended solids, which are light and fluffy and are more difficult to dewater. Sometimes, organic or inorganic chemicals are added to improve the solids capture. To handle these solids, the sewage treatment system must come with a full STS package comprising the primary, secondary, tertiary treatment, and sludge thickening and dewatering system. In sewage treatment applications, several thickening and mechanical dewatering technologies are used. These include gravity thickening, flotation thickening, pressure filters, rotary vacuum filters, belt presses, and less commonly, sludge drying beds, or drying lagoons, or dryers. Before undergoing the mechanical dewatering process, the sludge may be chemically conditioned to improve its dewatering characteristics.

14.1 Polymer selection and dosage determination

Laboratory tests should be conducted to select the right polymer and determine its optimum dosage. Such tests include the capillary suction test or the Buchner funnel test. Results obtained from these tests must be kept for review and inspection.

14.2 Performance monitoring of sludge thickening systems

Some of the operating criteria of the common sludge thickening systems are given below as examples.

14.2.1 Gravity and flotation thickening

14.2.1.1 Air to solids ratio

Air to solids (A/S) ratio is calculated by using the formula:

$$\text{A/S ratio} = \frac{(\text{Air flow, m}^3\text{/min})\ (\text{Air density, kg/m}^3)}{(\text{Sludge flow, m}^3\text{/min})\ (\text{\% solids})\ (\text{Sludge density, kg/m}^3)}$$

14.2.1.2 Surface loading rate

Surface loading rate, which is the amount of sludge applied to the surface of gravity thickener, is calculated by using the formula:

$$\text{Surface loading rate} = \frac{\text{Sludge applied, m}^3\text{/d}}{\text{Thickener area, m}^2}$$

Surface loading rate is in units of $m^3/(m^2.\ d)$.

14.2.1.3 Solids loading rate

Solids loading rate (SLR) is the weight of sludge applied to the surface of gravity thickener. SLR is calculated by using the formula:

$$\text{SLR} = \frac{\text{(Sludge flow, m}^3\text{/d) (\% solids) (Sludge density, kg/m}^3\text{)}}{\text{Thickener area, m}^2}$$

SLR is in units of $kg/(m^2.\ d)$.

14.3 Performance monitoring of sludge dewatering systems

14.3.1 Vacuum filter yield

Vacuum filter yield is the weight of sludge applied per unit area of the filter. It is calculated by using the formula:

$$\text{Vacuum filter yield} = \frac{\text{(Sludge flow, m}^3\text{/d) (\% solids) (Sludge density, kg/m}^3\text{)}}{\text{Filter surface area, m}^2}$$

Vacuum filter yield is in units of $kg/(m^2.\ d)$.

14.3.2 Hydraulic loading rate for belt filter press

Hydraulic loading rate is the weight of sludge applied per meter of belt width. It is calculated by using the formula:

$$\text{Hydraulic loading rate} = \frac{\text{Sludge flow, m}^3\text{/d}}{\text{Belt width, m}}$$

Hydraulic loading rate is in units of $m^3/(m.\ d)$.

14.2.3 Kilograms of solids pressed for plate and frame filter press

Kilograms of solids pressed for hour is calculated by using the formula:

$$\text{Kilograms of solids pressed} = \frac{(\text{Sludge flow, m}^3\text{/d})\ (\%\ \text{solids})\ (\text{Sludge density, kg/m}^3)}{\text{Plate surface area, m}^2}$$

Hydraulic loading rate is in units of kg/(m^2. d).

14.3 Performance monitoring of sludge thickening and dewatering systems

Typically, performance monitoring of sludge thickening and dewatering systems is carried out by performing the above calculations and comparing the calculated values with typical values used in practice. Typical values may vary from situation to situation depending on many factors such as design of system, sludge characteristics, type of chemicals used, etc.

CHAPTER 15:
ANALYSIS OF PERFORMANCE MONITORING DATA

CHAPTER 15 –ANALYSIS OF PERFORMANCE MONITORING DATA

The performance monitoring activities generate lots of data and over a period of time a huge amount of performance monitoring data will be accumulated. This raw data must be massaged suitably to generate easy to understand and useful information to be used for a variety of purposes. The data could be used for trend analysis, compliance demonstration, facilities maintenance planning, budget allocation, etc. This chapter is dedicated to the discussion of the common data analytical methods to transform the data obtained from the performance monitoring activities and translate them into ready to use information. The methods of data analysis discussed in this chapter are only minimum recommended procedures to assist the STS operators or supervisors on how to tabulate, interpret and present data in a systematic and technically acceptable fashion. Other methods can be accepted for the data analysis if they provide better representation of the data and better suit the industry's specific requirements and style.

In this chapter the performance monitoring data of biological treatment processes (BPs) will be used as an example of how data analysis is done.

15.1 Transforming raw data to descriptive statistics

The PM activities of BPs yield data, which can be categorized into two different categories, namely "direct measurements" and "computed data". Direct measurements include data on flowrate, pH, oxidation reduction potential (ORP), temperature, dissolved oxygen (DO), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), settled sludge volume in 30 minutes settling test (SV_{30}), nitrogen (N) and phosphorus (P). The above data is obtained either from equipment readings, field tests, flow readings or from measurements or laboratory tests. Computed data include sludge volume index (SVI), oxygen uptake rate (OUR), specific oxygen uptake rate (SOUR), food to microorganism (F/M) ratio, return flow (Q_R), return rate (Q_R/Q), hydraulic retention time (HRT), detention time (DT), solids inventory (SI), sludge age (θ_c), and wasting rate (Q_W).

The above data is then converted to descriptive statistics by using a statistical package. Descriptive statistics can include numerical summaries and graphical summaries. Numerical summaries include mean, median, mode, range, variance, and standard deviation, while graphical summaries include the histogram, dispersion graphs and trend charts.

15.2 Comparing the computed statistics with the recommended ranges

The statistics computed earlier must be presented in a suitable format for reference, ease of comparison, and effective communication between the STS personnel and the others. The recommended table by which the computed statistics can be presented is shown in Table 14.1. The performance monitoring data which includes data on pH, dissolved oxygen, MLSS, MLVSS, BOD, COD, nutrients, SVI, OUR, SOUR, SV_{30}, SVI, F/M, Q_R, Q_R/Q, HRT, SI, θ_c, and Q_W as well as the recommended ranges are shown in this table. The recommended ranges for most of the PM parameters have been highlighted in chapters 10, 11, and 12. Any parameter which falls outside the recommended ranges is easily noticed, thereby, speedy attention can be given. Sometimes, the situation calls for immediate corrective actions to be taken. In other situations, it calls for further investigation to determine or confirm the cause of the problem. Whatever the circumstances are, for the most part, timely action is necessary in order to avoid the worsening of situations leading to effluent noncompliance problems.

15.3 Performance monitoring control charts (PM control charts)

Performance monitoring control charts (PM control charts) are plotted as an upper line for the upper control limit (UCL) and a lower line for the lower control limit (LCL). The control limits are generally dictated by the technical characteristics of the treatment process to be controlled or design criteria used by the design engineers at the design stage. The control limits are also the recommended ranges discussed in chapter 10, 11, and 12. PM charts of various parameters such as F/M ratio, DO, MLSS, influent BOD and COD, effluent BOD and COD, SVI, SOUR, and θ_c versus time can be plotted on the graphs to evaluate treatment process control performance and its stability.

15.4 Summary reports

The daily performance monitoring results can be summarized in a simple Table as shown in Table 15.1. Summary Reports can be prepared to summarize the status of STS performance based on the descriptive statistics that have been tabulated in Table 10.1. Such reports can be regularly submitted to the Environmental Performance Monitoring Committee (EPMC) or factory management. Examples of Summary Reports are illustrated in the Appendices.

Table 15.1: Example of daily performance monitoring test results for an activated sludge system

Type of process: EAAS
Operator's name: ....
Competent person's name: ....
Shift number: ....
Date: ....Time:..................................

Sampling Location Parameter	Parameter	Units	Value/ Remarks	Recommended range
Influent or Equalization tank	Q	m^3/d		Design value
	BOD	mg/L		Design value
	COD	mg/L		Design value
	pH	-		Actual condition
	T	°C		Actual condition
	TIN	mg/L		Actual condition
	P	mg/L		Actual condition
	BOD:TIN:P	-		100:5:1
Aeration tank	DO	mg/L		2.5 to 3.5 (for nitrifying system)
	X	mg/L		3,000 to 6,000
	SV_{30}	mL/L		-
	SVI	mL/g		50 to 100
	pH	-		6.5 to 8.5
	X_{RAS}	mg/L		Actual condition
	X_{WAS}	mg/L		Actual condition
	Q_R	m^3/d		Actual condition
	Q_R/Q	%		50 to 150
	Q_W	m^3/d		-
	F/M ratio	kg/(kg.d)		0.05 to 0.15
	OUR	$mgO_2/(L.h)$		-
	SOUR	mgO_2/h per g MLVSS		8 to 20
	Microscopic examination	-		-
Secondary clarifier	BOD	mg/L		Standard A or B
	COD	mg/L		Standard A or B

	DO	mg/L		-
	pH	-		Standard A or B
	TIN	mg/L		1.0
	P	mg/L		0.5 to 1.0
	Overall BOD removal	%		-
	Sludge blanket	m		-
	Weir cleaning	-		-

Similar tables can be developed for other BPs (such as lagoon systems or attached growth systems) and PCPs, if provided in the STS treatment train.

15.5 Frequency of report preparation

Performance monitoring data should be analyzed as frequent as possible, preferably at a minimum, on a monthly basis, at the end of every month. Monthly performance monitoring charts and summary reports are also prepared.

CHAPTER 16:
TROUBLE SHOOTING

CHAPTER 16: TROUBLE SHOOTING

As they say, life is not always a bed of roses. Sometime, troubles crop up along the way. Troubles are a part of life that one has to accept and deal with in the best manner. In the course of operating a sewage treatment system (STS), the STS operators may face operational troubles at the STS. This chapter is dedicated to the discussion of typical problems, that are commonly encountered in the day to day operation of lagoon systems, attached growth systems and suspended growth systems (activated sludge systems), what their root causes are, and how to address them.

LAGOONS

16.1 Common causes of lagoon effluent noncompliance

Typical causes of lagoon effluent violations are organic overloading, short-circuiting, algal overgrowth, sludge accumulation and nitrification, or partial nitrification. These are discussed briefly below.

16.1.1 Organic overloading

Organic overloading can be caused by influent organic shock loads. An immediate remedial action to an organic overload problem is to increase increase organic treatment capacity by increasing aeration. On a longer term, the cause of the organic overload must be identified and a permanent solution found. If the STS is serving the public, an illegal discharge from unauthorized source such as industry, may be the cause of the increased organic load.

16.1.2 Shortcircuiting

The impact of shortcircuiting is that the sewage does not have sufficient detention time to receive full treatment. Shortcircuiting can be caused by design factors such as such as poor inlet and/or outlet design, inadequate lagoon's length-to-width ratio, or operational factors sch as poor mixing and improper aerator placement, or temperature stratification. The occurrence of shortcircuiting can be verified by conducting a DO and temperature profile test.

Remedial actions to address shortcicuiting problems depend on the root causes identified. Possible solutions may be relocating aerators, adding aerators and mixers, adding baffles, recirculating to enhance mixing, and redesigning inlet and outlet structures to include manifolds.

16.1.3 Algal overgrowth

Algal growth is promoted by several factors such as long detention times, shallow pond depths, abundant nutrients, and sunshine. The abundant algal growth can be easily observed and may result in high efffluent TSS. During night time, both the aeobic bacteria and algae utilize DO for respiration, causing a depletion of DO in the early mornings. To address the algal growth problem, the aerator running time is increased or more aerators are turned on during the night. Other remedial actions actions could be adding a floating cover or a physical shade over the lagoon's surface to block the sunlight. In extreme cases, an approved agrocide can be used to kill the algae. To prevent the discharge of treated effluent containing algae, discharge from the lagoon should be drawn off not from the lagoon's surface but from various depths of the lagoon.

16.1.4 Sludge accumulation in lagoons

Over years of operation, sludge may accumulate in the lagoons. The impact of high sludge accumulation may be reflected in decreased treatment efficiency due to decreased HRT. A temporary response action is to increase aerator running time or to add additional reactors in the lagoons. An obvious long term solution is to perform lagoon desludging. Desludging operations must comply with desludging rules and guidelines imposed by the DOE and other authorities.

16.1.5 Partial nitrification

In order to comply with the legal requirements on the control of ammonia and nitrates, lagoons are required to nitrify. The problem of partial nitrification is indicated by high BOD5, COD, low DO and moderate NH3 concentrations. The response would be to increase aeration by increasing aerator running time.

16.1.6 Odorous emission

Odor can be a problem with anaerobic lagoons. Remedial actions to address odorous emission include recirculating lagoon effluent, adding sodium nitrate, providing a mixer to break up scums on the lagoons surface which trap the odorous gases.

ACTIVATED SLUDGE SYSTEM

In the next section, typical problems encountered in the operation of activated sludge systems are discussed and possible remedies are suggested.

16.2 Odors from primary clarifiers

If odors are detected from the primary clarifiers, it indicates that the sludge in the clarifier has become septic and anaerobic biodegradation has started. The sludge holding time in the clarifier should be just enough to thicken the settled sludge but not too long that septic conditions develop. Typically, a one hour sludge holding time is considered sufficient. If odorous gases are detected, the response action would be to increase the sludge removal rate from the clarifier.

16.3 Common problems in ASTS operation

The most common problems in the operation of an activated sludge systems are encountered in the clarification stage i.e. in the secondary clarifier. The problems are bulking sludge, rising sludge, and foam. All of the above phenomena lead to "settling problems" in the secondary clarifier which results in the occurrence of turbid and noncompliant effluent.

16.3.1 Bulking sludge

Bulking sludge is a phenomenon where sludge exhibits poor settling characteristics and poor compactability. The symptoms of bulking sludge include high TSS concentration in the secondary clarifier effluent, high SVI, and abundance of filamentous organisms in the mixed liquor. Operational causes of filamentous bulking include:

- Low DO in the aeration tank
- Low pH

- Insufficient nutrients in aeration tank influent
- Widely varying organic waste loading
- High organic loading
- High F/M
- High oil and grease or sulfide
- Septicity

Investigative reponses include:

- Measuring SVI
- Performing microscopic examination
- Monitoring DO
- Monitoring pH
- Checking F/M
- Checking sludge age
- Checking organic loading
- Checking toxicity of sewage influent

The remedial actions to bulking sludge depends on the causes identified and my include:

- Decreasing F/M by wasting less
- Increasing DO by increasing aeration or adding an oxygen source such as sodium nitrate
- Increasing pH by using caustic, lime or magnesium hydroxide
- Correcting nutrient balance by adding N, P
- Applying coagulants such as ferric chloride
- Applying chemical oxidation of RAS (use chlorine or hydrogen peroxide)

16.3.2 Rising sludge

Rising sludge occurs in secondary clarifiers where the sludge is observed to rise or float to the clarifier surface. This is commonly referred to as "rising sludge or "clumping". The biological oxidation of an organic effluent which contains both organic matter and nitrogen (ammonia) occurs in two phases. The first phase is the microbial oxidation of the organic matter which is followed by followed by the biological oxidation of ammonia (also known as nitrification). The nitrates that are formed in the aeration tank then flow into the secondary clarifier. If the dissolved oxygen levels are sufficiently low in the secondary clarifier and there is some organic matter available, denitrificaton will take place as a result of the actions of several groups of anoxic bacteria (denitrifiers). The nitrates will be converted to nitrogen gas which gets attached to the sludge mass causing it to become buoyant and rise to the surface. Rising sludge can easily be differentiated from a bulking sludge by noting the presence of small gas bubbles attached to the floating solids.

An immediate remedial action to rising sludge is to increase the RAS pumping rate to reduce sludge blanket depth and sludge retention time in the clarifier. A long term solution is to provide an anoxic reactor for the denitrification to take place instead of occuring in the clarifer.

16.3.3 Ashing

Ashing describes the occurrence of fine sludge particles in secondary clarifiers. It is a sign of overoxidized mixed liquor that could happen in extended aeration activated sludge systems operated at high sludge ages. A remedial action to ashing will be to reduce the sludge age by increasing wasting.

16.3.4 Foaming

Foam caused by Nocardia appears as viscous brown foam that covers the aeration tanks and secondary clarifiers. Foaming may cause safety issue and nuisance to neighbors when the foam sweeps onto nearby roadways. Probable causes of the promoted growth of slow growing filamentous organisms (Nocardia) are high oil and grease, low F/M in the aeration tank, high MLSS due to insufficient sludge wasting and sludge reaeration.

Remedial actions to control foaming include reducing sludge age by increasing wasting, removing the source of high oil and grease, and even spraying with powerful water jets to force the foam out of the aeration tanks. Foam can also be skimmed and suctioned off from the tank. On a longer term, scum traps and selctor tanks can be introduced in the treatment train.

16.4 Microscopic examination

People say, a picture speaks a thousand words. In the quest to find the root causes of the ASTS operational problems (bulking sludge, rising sludge and Nocordia foaming), there is nothing better than to firstly, take a sample of the mixed liquor or the foam and examine it under the microscope. Microscopic examination will help us identify the causes of the problem, whether the problem is caused by filamentous organism(s) or not, and what organisms are involved. The above information is important because it will point to the right direction for the next steps to take to remedy the situation.

Table 16.1 below summarizes the types of filamentous organism involved with different causative conditions (environmental factors).

Table 16.1: A summary of the types of filamentous organism involved with different causative conditions (Source: Richard, 2014)

Causative Condition (1)	**Causative Filament Types**
Low dissolved oxygen (for the applied organic loading)	*S. natans*, type 1701 and *H. hydrossis*.
Low organic loading rate >(low F/M)	*M.parvicella*, *Nocardia* spp., and types 0041, 0675, 1851 and 0803.
Septic wastes / Sulfides (high organic acids)	*Thiothrix I* and *II*, *Beggiatoa* spp., *N. limicola II**, and types 021N, 0092*, 0914*, 0581*, 0961* and 0411.
Nutrient deficiency - N and/or P (industrial wastes only) nitrogen - phosphorus -	*Thiothrix I* and *II* and type 021N. *N. limicola III*
Low pH (<pH 6.0)	Fungi
High oil and grease	*Nocardia* spp., *M. parvicella* and type 1863

(1) Note that some filaments occur at several conditions. * These filaments occur at lower F/M at septic conditions.

Once the type of causative filamentous organisms responsible for the bulking sludge has been identified (the second column) through microscopic examination, then identify the possible causative conditions as summarized in Table 1 (the first column). Then, start taking remedial actions to correct the causative conditions.

TRICKLING FILTERS

In the following sections typical problems encountered in the operation of trickling filters and rotating biological contactors are discussed briefly and possible remedial actions highlighted.

16.5 Trickling filter operational problems and solutions

Typical operational problems include filter ponding, odors, high effluent BOD and TSS, and filter flies. Possible remedial actions include:

- Removing debris from filter media

- Using high pressure jets to agitate ponded area
- Checking for excessive organic overloading
- Checking for poor ventilation
- Check for short circuiting
- Checking for excessive sloughing
- Improving housekeeping
- Checking for insuficient recirculation

16.6 Rotating biological contactor operational problems and solutions

Operational problems associated with the operation of rotating biological contactors include: formation of white slime on disk area indicating high sulfur content; excessive sloughing which could be due to excessive pH fluctuations; solids accumulating in the reactor due to inadequate treament; and mechanical problems, such as uneven RBC rotation, shaft running hot, etc. Possible remedial actions could include:

- Aerating of RBC influent or adding sodium nitrate or hydrogen peroxide
- Installing pH control instrument
- Checking and correcting grit removal or primary settling problems
- Solving mechanical problems by following manufacturers' instructions

CHAPTER 17:

PERFORMANCE MONITORING INSTRUMENTS

MODULE 17: PERFORMANCE MONITORING INSTRUMENTS

The operators of the sewage treatment systems require a set of instruments available at their disposal in order to monitor the processes occurring in the treatment components. These are the performance monitoring instruments. These instruments form part and parcel of the operation and maintenance of the STS. The instruments yield important data, which would indicate whether the processes in the treatment components are occurring in an optimal fashion. Operational changes to the operation of the STS, if required, will be based on the information obtained by the use of these instruments.

17.1 Suggested performance monitoring instruments

In the operation of STS, the following instruments are relevant for conducting performance monitoring of the STS processes.

- pH meter
- DO meter
- ORP meter
- BOD associated equipment and on line BOD analyzers
- COD reactor and spectrophotometer
- TOC meter and associated equipment
- SS meter
- 'Sludge Judge", sludge gun, automatic sludge depth meters
- Graduated cylinder, settleometer, Imhoff cone
- Respirometer
- Spectrophotometer
- Thermometer
- Turbidity meter
- Ammonia, nitrite, nitrate measuring instruments
- Pressure gage
- Flow meter and totalizer
- Interface level analyzer

Some of the instruments listed above are more relevant to certain treatment processes than others.

Some photos of the instruments are given below.

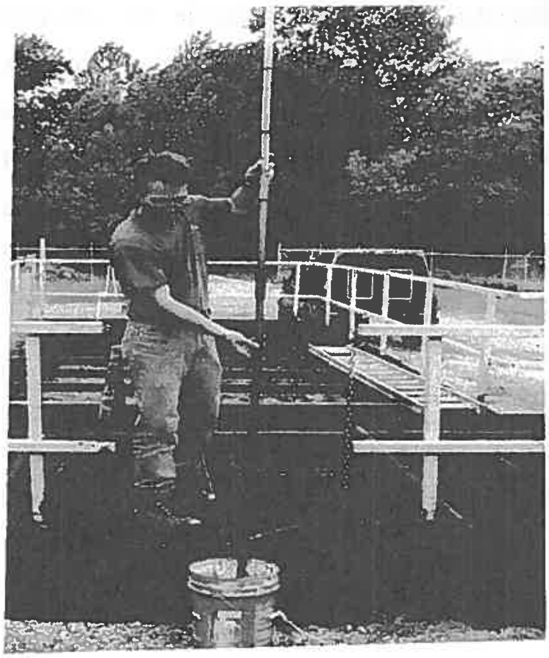

Fig. 17.1(a) : Measuring sludge depth in secondary clarifer using sludge judge (source: Ohio EPD)

Fig. 17.1(b): Sludge judge

Fig. 17(c) Sludge gun

Fig. 17.2(a): Taking sample form aeration tank setlleometer test

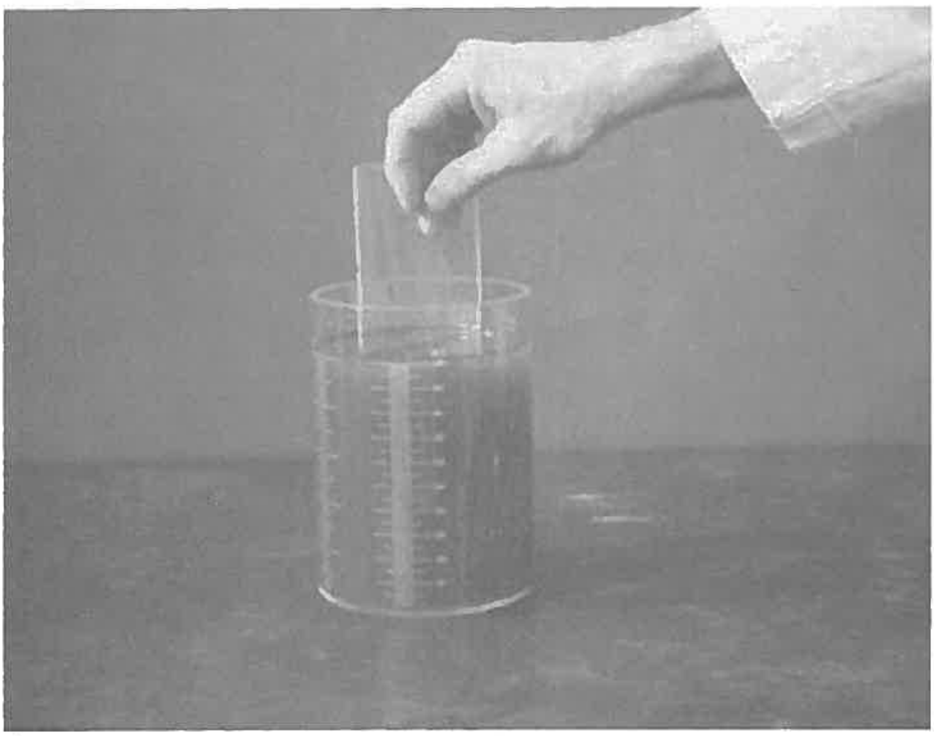

Fig. 17.2: Performing setlleometer test (SV_{30}) using a graduated cylinder

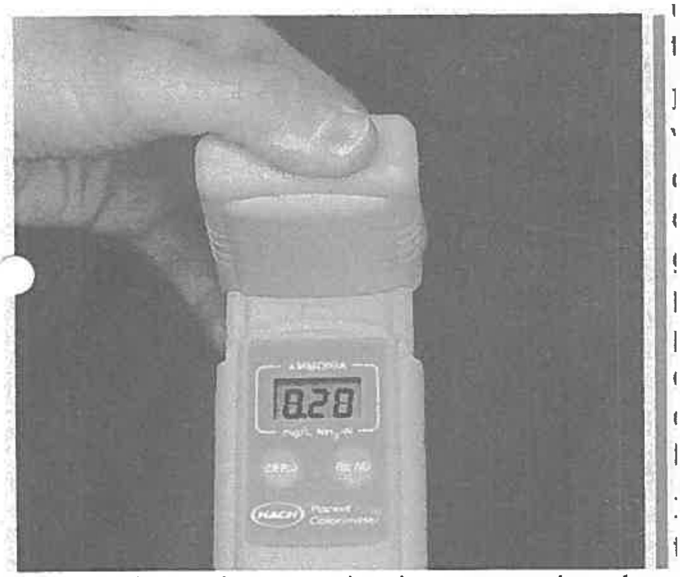

Fig. 17.3: Measuring ammonia using an ammonia analyzer

Fig. 17.4: Online ammonia, nitrite, and nitrate monitoring

Fig. 17.5: ORP meter

Fig. 17.6: pH and ORP meter

Fig. 17.7: Suspended solids meter

Fig. 17.8: pH and ORP meter

Fig. 17.9: Respirometer

Fig. 17.10: COD reactor

Fig. 17.11: DO meter and BOD bottle

17.2 Maintenance of performance monitoring instruments

The performance monitoring instruments must be maintained and calibrated according to the manufacturers' instructions. The importance of instrument maintenance and calibration cannot be over emphasized. Maintenance and calibration records must be kept for internal reviews and for inspectional purposes.

CHAPTER 18:

MAINTENANCE OF STS COMPONENTS

MODULE 18: MAINTENANCE OF STS COMPONENTS

To accomplish a success story in the treatment of industrial effluents, not only the STS must be designed adequately, the STS hardware must also be maintained in smooth working conditions and the processes occurring in the various treatment components must be operated optimally. All the above factors must be given adequate attention in order to ensure quality effluent is produced on a sustained basis.

18.1 Maintenance of STS hardware components

Proper functioning of the STS hardware is a prerequisite to achieving success in the operation of the STS. Proper functioning of the hardware depends on their maintenance which will keep them running and operating in an optimal manner. Whether an STS is a small, simple system such as the septic tank serving just a few hundred population equivalent (PE), or a large, complex, state of the art system, such as the activated sludge systems serving several thousand PE, a comprehensive operation and maintenance (O&M) plan must be drawn up and implemented. O&M plan must include both aspects of maintenance: preventive maintenance and corrective maintenance. The preventive maintenance in turn consists of periodic maintenance and predictive maintenance of the structural, mechanical and electrical engineering components and equipment to prevent structural, mechanical and electrical failures from occurring. Corrective maintenance addresses and fixes the problems after they have occurred. The O&M must cover both the STS structural, mechanical, and electrical components and performance monitoring equipment and instrumentation system.

The STS hardware includes a whole range of structural and mechanical components such as pumps, screens, aeration tanks, aeration system (blowers, compressors), mixers, skimmers, equalization tank, pH adjustment tank, precipitation tank, carbon adsorption column, dissolved air flotation system, piping system, valves, motors, chemical dosing systems, chemical storage tanks, clarifiers, etc. Electrical components may also form an essential part of the STS. Successful achievement of the goal to treat the raw sewage and produce compliant effluent on a continuous basis depends on the uninterrupted operation of all the STS components. The latter in turn depends on rigorous implementation of the O&M plan. The importance of O&M

cannot be overemphasized and it needs to be performed in accordance with the procedure specified in the manuals produced by the manufacturers. The O&M of the performance monitoring instruments has been discussed in chapter 17.

CHAPTER 19:

RECORD KEEPING REQUIREMENTS

CHAPTER 19: RECORD KEEPING REQUIREMENTS

Sewage sources are required to maintain records on the operation and maintenance of the sewage treatment systems and the discharge. Legal provisions on record keeping requirements are stipulated in regulation 10 on sewage discharge and regulation 20 on operation, maintenance, and performance monitoring of the STS. Record keeping serves many important purposes such as hardware performance reviews, compliance assessment, hardware maintenance planning, etc. Additional records relating to STS operation is the STS staff training records.

19.1 Maintenance of dedicated files

A file must be kept for each piece of equipment or instrument which contains the operator's manual, the preventive and corrective maintenance schedule, and records of all maintenance and repairs performed, including exact nature of the problem, the date of repair, what was done, and who did it. Examples of meter calibration logs and instrument maintenance and repair records are shown in the Appendices. Records of upset conditions whether they are minor or major must also be maintained as well as corrective actions taken to address the problems must also be maintained. The date, nature of upset, and the personnel involved in making decisions and solving of the upsets must be recorded.

CHAPTER 20:

ENVIRONMENTAL MAINSTREAMING

CHAPTER 20-ENVIRONMENTAL MAINSTREAMING

The Department of Environment (DOE) has embarked on a program known as "Guided Self-Regulation" (GSR) to develop an industrial society that has an intrinsic culture of pride in environmental excellence (EE). The program cuts across all the sectors regulated under the Environmental Quality Act. To assist the regulated sectors to achieve the state of self-regulation, the DOE has formulated a set of environmental mainstreaming (EM) tools to be implemented in the organizations, industrial premises, businesses, development projects, and activities, which come under the purview of the EQA. The EM tools include:

- Environmental policy (EP)
- Environmental budgeting (EB)
- Environmental monitoring committee (EMC)
- Environmental facility (EF)
- Environmental competency (EC)
- Environmental reporting and communication (ERC)
- Environmental transparency (ET)

The EM tools are briefly explained in the following sections.

20.1 Environmental policy (EP)

The environmental policy (EP) of successful organizations uses strong and unequivocal statements to convey their environmental commitment to their employees, clients, stakeholders and the public. The EP is disseminated to all relevant parties and translated into action in the organization's work procedures, materials purchasing policy, and business decision making process and cascades down to the supply chain.

20.2 Environmental budgeting (EB)

Sufficient budget must be set aside solely for the purpose of taking measures to comply with the environmental regulatory requirements and other environmental-related efforts. At the design stage, budget must be available for the design and installation of the pollution control facilities, while at the operational stage, budget must be allocated for proper operation and maintenance of pollution control systems and management of waste generated by the organization. The environmental budget also includes the cost for setting up of laboratory facilities, provision of personnel, and purchase of performance monitoring equipment.

20.3 Environmental monitoring committee (EMC)

The success of an organization to comply with the environmental requirements is contingent upon the relevant personnel in different departments in the organization playing their role in an effective manner. To promote collective responsibility to be environmentally compliant, two monitoring committees are set up: one at the working level, the other at the policy level. At the working level, the committee known as the environmental performance monitoring committee (EPMC) is chaired by a senior official of the organization and it meets on a monthly basis, or at a minimum, once in a quarter. At the policy level, the committee is known as the environmental regulatory compliance monitoring committee (ERCMC), which meets at a minimum, once a year. The chief executive officer or chairman of the organization chairs the ERCMC.

20.4 Environmental facility (EF)

The primary components of the environmental facilities (EFs) include industrial effluent treatment system, sewage treatment system, air pollution control system and associated support facilities such as laboratory, performance monitoring equipment, on-line instrumentation system, and waste management infrastructure. The above form an integral part of the organization's overall infrastructural planning, which cannot be compromised.

20.5 Environmental competency (EC)

The relevant personnel involved in discharging various environmental responsibilities within an organization need to possess the required competencies. The personnel include those who have been assigned the task to perform DOE-regulated functions: to manage waste and supervise the operation of air pollution control, effluent and sewage treatment systems. The organizations must draw up a comprehensive training program to produce competent persons and trained support staff to ensure full compliance with the DOE requirements in the regulated activities.

20.6 Environmental reporting and communication (ERC)

A formal communication channel must be established for reporting environmental concerns and system upsets which warrant prompt actions to be instituted. Internal reporting can be initiated to report on a regular basis the regulatory compliance status of the organization to the chief executive officer (CEO) and various heads of the department within the organization. Updates of new environmental requirements and their implications can be disseminated to the relevant personnel in the organization. ERC requires systematic analysis of PM data, which must be summarized in appropriate format for easy understanding and communication and maintained for management review purposes.

20.7 Environmental transparency (ET)

To foster rapport with the immediate neighbors, promote green image, and improve public confidence, organizations are encouraged to be more transparent in their environmental compliance and achievement. Compliance status can be displayed on website or billboard located at the boundary or entrance to the organization's premise. An environmental sustainability report can be prepared for the organization to showcase its success in managing the environmental concerns of the organization and minimizing the environmental footprint of its business. The corporate image of the organization is markedly enhanced through environmental transparency.

20.8 Environmental mainstreaming leads to environmental excellence

Rigorous implementation of the above EM tools by the regulated sectors will result in creating organizations and businesses which are successful and at the same time take pride in their achievement of environmental excellence (EE). EE is exhibited in the intrinsic values of being environment conscious (where environmental agenda is factored into the organization's management and decision making process), achievement of sustained environmental regulatory compliance, high degree of environmental transparency and accountability, and strong commitment to continuous environmental improvement. Highly successful organizations are also exemplary in their environmental compliance and achievements, which go beyond regulatory requirements.

CHAPTER 21:

CONCLUSIONS

21- CONCLUSION

The shift of focus from compliance monitoring to performance monitoring represents a new dimension to operating and monitoring the pollution control systems. By understanding the processes occurring in the treatment components and what factors affect them, an STS operator has a better control of the STS. Through close monitoring of the processes, over time the operator develops an intimate relationship with his STS to the extent that he can read signs of system upsets through the tell tale signs provided by the performance monitoring parameters. In such situations, immediate corrective actions can be instituted, preventing major STS upsets that may lead to discharge noncompliance.

Performance monitoring is a proactive technical procedure that provides a win-win strategy for all, i.e. the regulated sectors, the Department of Environment (DOE), and the environment, which culminates in the improvement in regulatory compliance, enhancement of organizations' corporate image, and the amelioration of water quality of our rivers.

IMPORTANT NOTICE

The specifications in this Guidance Document represent the minimum requirements to be complied with by the sewage dischargers for conducting performance monitoring of their STSs. Nevertheless, the DOE assumes no responsibility for the accuracy, adequacy, or completeness of the concepts, methodologies, or protocols described in this Document. The STS owners shall take additional measures where deemed appropriate to further ensure compliance with the effluent discharge standards stipulated in the Sewage Regulations. Compliance with the regulatory requirements and standards is solely the responsibility of the dischargers.

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Appendix A

Record of Performance Monitoring of Screen (Primary treatment-Pretreatment)
Date:………..; Month:………………..

Time/Date*	Flow rate, m^3/h	Screenings characteristics			Operational parameters		Remarks	Signature	
		Quantity, m^3/d	Moisture, %	VS, % of TSS	**Headloss, mm	***Velocity, m/s		****	*****
Monthly mean									

Notes:
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** Typical allowable headloss: 0.1 to 0.2 m
*** Typical allowable velocity: 0.3 to 0.5 (manually cleaned); 0.5 to 1.0 (mechanically cleaned)
**** ***** One of the signatures must be by a competent person
Routine inspections, lubrication and adjustments should also be recorded

Appendix B

Record of Performance Monitoring of Aerated Grit Chamber (Primary Treatment-Pretreatment)
Date:………..; Month:……………..…

Time/Date*	Flow rate, m^3/h	Grit characteristics			Operational Parameters				Remarks	Signature	
		Quantity, m^3/d	Moisture, %	VS, % of TSS	Velocity, m/s	HRT, min	Airflow rate, m^3/h	Power, kW		**	***
Monthly mean											

Notes:
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** *** One of the signatures must be by a competent person
Routine inspections, lubrication and adjustments should also be recorded

Appendix C

Record of Performance Monitoring of Equalization Tank (raw sewage) (Primary Treatment-Pretreatment)
Date:...........; Month:..................

Time/Date*	Flow rate, m^3/h	BOD_5, mg/L	COD, mg/L	pH	SS, mg/L	O&G, mg/L	Nutrients, mg/L	Remarks	Signature	
									**	***
Monthly mean										

Notes:
* Choose which ever is applicable
CP needs to decide on significant parameters to monitor
Frequency of sampling and analysis: daily or as deemed appropriate
Nutrients: N, P
** *** One of the signatures must be by a competent person

Appendix D

Record of Performance Monitoring of Primary Clarifier (Primary Treatment-)
Date:………..; Month:……………..…

Time/Date*	Flow rate, m^3/h	Sludge characteristics			Operational Parameters				Efficiency parameters				Signature	
		Quantity, m^3/d	TSS, mg/L	VSS, %	SOR, $m^3/(m^2.d)$	HRT, h	WOR, $m^3/(m.d)$	SLR, $kg/(m^2.d)$	BOD_{in} mg/L	BOD_{out} mg/L	TSS_{in} mg/L	TSS_{out} mg/L	**	***
Monthly mean														

Notes:
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** *** One of the signatures must be by a competent person
Routine inspections, lubrication and adjustments should also be recorded

Appendix E

Record of Performance Monitoring of Aeration Tank (Secondary Treatment)
Date:………..; Month:……………..…

Time/ Date*	DO, mg/L	MLSS, mg/L	MLVSS, mg/L	SVI, mL/mg	pH	X_{RAS}, m^3/d	X_{WAS}, m^3/d	Q_{RAS}, m^3/d	Q_{WAS}, m^3/d	θ, d	F/M, kg/kg	SOUR, mg/(g.h)	BOD Removal efficiency	Signature	
														***	****

Notes:
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** *** One of the signatures must be by a competent person
Routine observations of aeration tank sludge color, occurrence of foaming, etc. should also be recorded

Appendix F

Record of Performance Monitoring Activity: Oxygen Uptake Rate (OUR) Test Results (Secondary Treatment)
Test performed by.........................*Signature......................... Date...................... Reviewed by.........................**Signature.........................
Date.........................

(Example)

Time	DO, mg/L

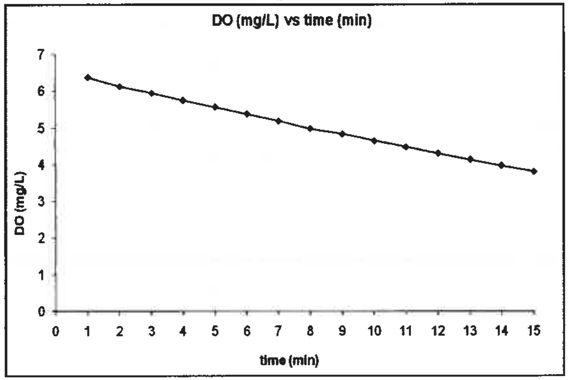


Fig 1: DO versus Time

OUR = Gradient of graph as shown in Fig 1. Units of OUR: $mgO_2/(L/h)$

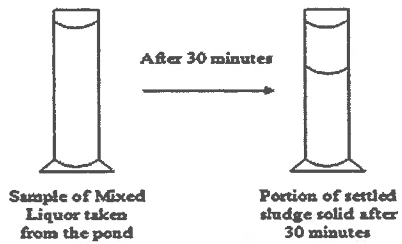
SOUR = OUR/MLVSS........... Units of SOUR: mgO_2 per h/(g MLVSS)

Notes:
* ** One of the signatures must be by a competent person
Frequency of performing OUR Test: Ranges from once a day to once a week depending on variability of influent characteristics and other factors

Appendix G

Record of Performance Monitoring Activity: Sludge Volume Index (SVI) Test Results (Secondary Treatment)
Test performed by……………………..*Signature…………………….. Date…………………… Reviewed by……………………..**Signature……………………..
Date………………….…

Results:



Settled sludge volume (SV_{30})……… mL/L

MLSS =…………..mg/L

$$\text{SVI, mL/g} = \frac{SV_{30}\text{, mL/L} \times 1000\text{ mg/g}}{\text{MLSS, mg/L}}$$

Notes:
* ** One of the signatures must be by a competent person
Frequency of performing SVI Test: Ranges from once a day to once a week

Appendix H

Record of Performance Monitoring of Membrane Filtration Unit in Membrane Bioreactor (MBR) System (Secondary Treatment)
(Note: MBR is used in combination with AS system. See Appendix E for Record of Performance Monitoring of Aeration Tank)

Date:……….; Month:………………..…

Time/ Date*	TMP, bar	System vacuum pressure, bar	Membrane scour air flowrate, m^3/min	Membrane cleaning	Membrane backflushing	Remarks	Signature	
							**	***

Notes:
TMP = transmembrane pressure
* Choose which ever is applicable
Frequency of monitoring: daily or as deemed appropriate
** *** One of the signatures must be by a competent person

Appendix I

Record of Performance Monitoring of Trickling Filter (Secondary Treatment)
Date:..........; Month:..................

Time/ Date*	Influent			Recirculated flow			Effluent					Remarks	Signature	
	DO	pH	T	DO	pH	T	DO	pH	SS,	Settleable solids	BOD		**	***

Notes:
All units in mg/L except pH in pH value and T in °C
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** *** One of the signatures must be by a competent person
Routine maintenance and observations of filter conditions such as filter ponding, detection of odors, etc. should also be recorded

Appendix J

Record of Performance Monitoring of Rotating Biological Contactor (Secondary Treatment)
Date:……….; Month:……………..…

Time/ Date*	Influent						Drum	Effluent					Remarks	Signature	
	DO	pH	T	SS	Settleable solids	BOD	Rotation speed	DO	pH	SS	Settleable solids	BOD		**	***

Notes:
All units in mg/L except pH in pH value, T in °C and drum rotation speed in mm/s
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** *** One of the signatures must be by a competent person
Routine maintenance and observations of RBC conditions such as media color, appearance, detection of odors, etc. should also be recorded

Appendix K

Record of Performance Monitoring of Ponding System (Secondary Treatment)
Date:………..; Month:……………….…

Time/ Date*	DO**			pH			Nutrients	BOD		COD		Q		VFA**	Alk**	Signature	
	Inlet	Middle	Outlet	Inlet	Middle	Outlet	Inlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Middle	Middle	***	****

Notes:
All units in mg/L except pH in pH value
* Choose which ever is applicable
** Not applicable to anaerobic ponds
Alk= Alkalinity
Frequency of sampling and analysis: daily or as deemed appropriate
*** **** One of the signatures must be by a competent person
Additional requirement: Sludge depth measurement
Routine pond maintenance and observations of pond conditions should also be recorded

Appendix L

Record of Performance Monitoring Data of Activated Sludge (Secondary Treatment)
Microscopic Examination

Date:………….; Time:……………….Performed by (Name and signature)*:……………..Checked by (Name and signature)**………..

* **Note: One of the signatures must be by a competent person

Microorganism group	Slide 1	Slide 2	Slide 3	Slide 4	Total
Ameoboids					
Flagellates					
Free swimming ciliates					
Rotifers					
Worms					

Relative importance
1……………..

2……………..

3……………..

Note:
Frequency of examination: daily or as deemed appropriate

Appendix M

Record of Performance Monitoring Data of Aeration Tank of Activated Sludge System (Secondary Treatment)

Nutrient Addition

Notes: Nutrient Ratio Guide -100BOD:5N:1P

General formula: Commercial chemical required, kg/d = $\dfrac{\text{Nutrient addition required, kg/d}}{\text{Decimal \%Nutrient x Decimal \% pure commercial chemical}}$

Example calculation for N requirement

E.g. Commercial chemical used: 80% anhydrous ammonia (NH_3)

Decimal %N in NH_3 = 14/17 = 0.82

Decimal % pure commercial chemical = 80% = 0.8

Nutrient addition required, kg/d = (Influent flowrate, m^3/d x Ammonia shortfall, mg/L)/1000

Ammonia shortfall = Ammonia required calculated from the nutrient ratio guide - Total ammonia present in raw effluent

Nutrients Addition

Date*	Flow rate, m^3/d	Raw effluent total ammonia, mg/L	Calculated ammonia required, mg/L	Chemical (N) addition required, kg/d	Raw effluent total orthophosphate, mg/L	Calculated orthophosphate required, mg/L	Chemical (P) addition required, kg/d	Signature	
								**	***

Notes:

* Choose which ever is applicable

** *** One of the signatures must be by a competent person

Appendix N

Record of Performance Monitoring of Secondary Clarifier (PCP used in combination with Secondary Treatment)
Date:…………; Month:……………..…

Time/ Date*	Flow rate, m^3/h	Operational Parameters						Efficiency parameters and observation				Signature	
		SOR, $m^3/(m^2.d)$	HRT, h	WOR, $m^3/(m.d)$	SLR, $kg/(m^2.d)$	Q_{RAS}, %	Sludge depth, m	TSS_{in} mg/L	TSS_{out} mg/L	Clarity	Sludge (wash out, floating, etc,)	**	***

Notes:
* Choose which ever is applicable
Frequency of sampling and analysis: daily or as deemed appropriate
** *** One of the signatures must be by a competent person
Routine weir cleaning and preventive & corrective maintenance should also be recorded

Appendix O

Record of Performance Monitoring Activity: Jar Test Results
Test performed by……………………..*Signature…………………….. Date……..…………… Reviewed by……………………..**Signature……………………..
Date…………………..…
Coagulant type…………………..……….
Coagulant dose…………..…mg/L

pH	SS, mg/L or Turbidity, NTU

(Example)

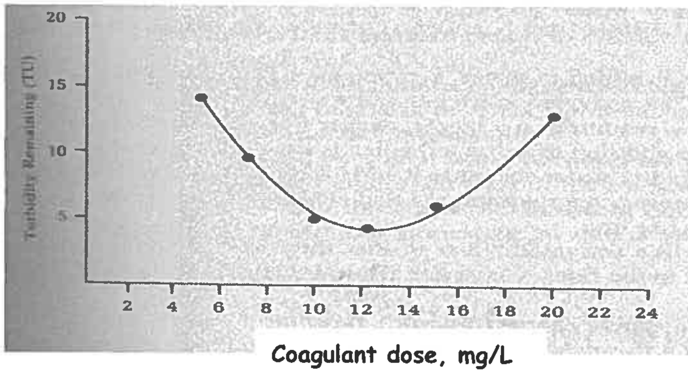


Fig 2: Graph of suspended solids or turbidity versus coagulant dose

pH……………

Coagulant dose, mg/L	SS, mg/L or Turbidity, NTU

Notes:
* ** one of the signatures must be by a competent person
Frequency of performing Jar Test: Performed if coagulant is used and frequency depends on variability of effluent characteristics

Appendix P

Calculation of chlorine dose for sludge bulking control

The chlorine dose is estimated based on SVI:

Chlorine dose, kg/d = SVI x F x W x 10^6

where: SVI = Sludge Volume Index, mL/g
F = Return sludge rate, m^3/d x 10^{-6}
W = RAS SS, mg/L

Calculation performed by:

Checked by: (competent person)

Date:

Frequency of performing dose calculations: Performed whenever required

Appendix Q

Record of Performance Monitoring Activities: Pressure Filters or Belt Presses*

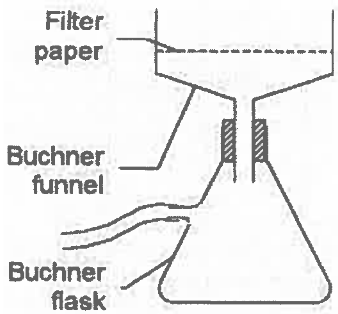


Fig 4: Buchner test assembly for determining coagulant dose

Buchner Test Results: Dosage kg/ton = (polymer solution, %) (Polymer added, mL) (2) / (SI volume, L) (SI solids, %) = ...

Test performed by.........................**Signature............... Date.......... Reviewed by...........***Signature.............. Date......

Month:...................

Date	Operation hours, h/d	Feed solids, %	Cake solids, %	Polymer use, g/kg dry TS	Solids capture, %	Sludge generated, kg	Signature	
							**	***

Note:
* The Table can be modified to suit the monitoring requirements for other types of dewatering equipment
** *** One of the signatures must be by a competent person

Appendix R

Record of Maintenance Activities of Communal Septic Tank/Imhoff Tank (Secondary Treatment)
Month...............

Date	Name of component or equipment	Nature of maintenance work	Name of contractor performing maintenance	Starting time and completion time	Remarks	Signature	
						**	***

Note:
* ** One of the signatures must be by a competent person

Appendix S

Record of Upset Conditions and Corrective Actions Taken to Address Them
Date:………..; Month:……………..…

*Date/Time Upset Condition Occurred	Nature of upset condition	Diagnosis of cause of upset condition	Any non compliance of discharge standard occurred? – Give explanation	Corrective action taken	When conditions returned to Normalcy	Remarks	Signature	
							**	***

Notes:
* Choose which ever is applicable
** *** One of the signatures must be by a competent person

Appendix T

Record of Maintenance Activities of STS Hardware Components
Month……………

Date	Time: from…… to……….	Name of STS component or equipment	Nature of maintenance work	Was the discharge stopped totally during the maintenance period? YES or NO	If effluent discharge was stopped, describe how effluent generated was managed	Remarks	Signature	
							**	***

Note:
* ** One of the signatures must be by a competent person

Appendix U

Record of Calibration Activities of STS Performance Monitoring Instruments
Month...............

Date	Name of PM instrument, make and model number	Nature of personnel who performed the calibration	Was the calibration performed according to the manufacturer's recommendation? YES or NO	Date of next calibration scheduled	Remarks	Signature	
						*	**

Note:
* ** One of the signatures must be by a competent person
Calibration records for all instruments must be maintained for inspectional purposes

Appendix V

Example of Summary Report for Activated Sludge System (Secondary Treatment)

Daily or Shift Summary Report:

Findings

Based on the performance monitoring conducted from 8 a.m. to 5 p.m. on Dec 3, 201.. and the data collected which were plotted as control charts (X-Y graph), the following conclusions can be made about the operation of the activated sludge system:

(a) The AS system was functioning in good operating condition with an overall BOD_5 removal efficiency of ....

(b)The operational parameters of SVI, OUR, SOUR, ... were all within the recommended ranges

(c) The mean DO level of......mg/L in the aeration tank was slightly on the low side

(d) The N:P ratio of ....was a little out of range on the low side

(e) The final effluent BOD_5 complied with the stipulated Standard A.

Recommendations

(a) The cause for the low DO in the aeration tank needs to be investigated and corrected promptly

(b) The N:P ratio which was out of range needs to be further investigated. Measurements may be repeated immediately to ascertain this finding.

Name of STS operator:............................Signature:.........................

Date & Time:............................

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