TEDP SERIES: DOE 1-2012

TECHNICAL EXPERTISE DEVELOPMENT PROGRAM
FOR DOE OFFICERS

Industrial Effluent Engineering



A PRIMER FOR DOE OFFICERS

RESOURCE BOOK FOR CePIETSI COURSE

DEPARTMENT OF ENVIRONMENT
Ministry of Natural Resources & Environment

FOR THE USE OF DOE STAFF ONLY

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Preface from the Director General

This Technical Guidance Document discusses the subject of **industrial effluent engineering** with a clear focus on those areas relevant to the job functions of the Department of Environment (DOE). The subject matter treated in the document is intentionally flavored with a **practical slant** consistent with the nature of functions assigned to the DOE.

The Guidance Document covers a wide range of topics including **effluent microbiology**, quantification of **organic content** and **principles and mechanisms** involved in the treatment of industrial effluents using **biological**, and **physical** and **chemical** methods. Additionally, a strong emphasis is given to the concept and implementation of **IETS performance monitoring,** a technical as well as management tool enforced through Industrial Effluent Regulations 2009 to advance the self regulation approach to the industries.

The understanding from the information contained this Guidance Document would equip DOE officers with sufficient knowledge enabling them to conduct the **review of proposals** for effluent treatment systems and identify appropriate **solutions** to industrial effluent treatment problems. It is our hope that a firm grasp of the subject of **industrial effluent engineering** will enable the DOE officers to make more technically sound programs and defensible decisions on matters related to industrial effluent treatment and industrial water pollution control.

HALIMAH HASSAN
Director General
Department of Environment
February, 2012

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LIST OF ABBREVIATIONS AND ACRONYMS

AS	Activated sludge
AL	Aerated lagoon
AN	Ammoniacal nitrogen
API	American petroleum institute separator
A/S	Air to solids
BOD	Biochemical oxygen demand
BP	Biological process
CePIETSO	Certified environmental professional in IETS operation
CePIETSI	Certified environmental professional in IETS Inspection
CePSWAM	Certified environmental professional in scheduled waste management
CMAS	Complete mix activated sludge
COD	Chemical oxygen demand
CPD	Continuous professional development
CPI	Corrugated plate interceptor
CSAS	Contact stabilization activated sludge
CSR	Corporate social responsibility
DAF	Dissolved air flotation
DO	Dissolved oxygen
DOE	Department of Environment, Malaysia
EAAS	Extended aeration activated sludge
EiMAS	Environment Institute of Malaysia
EQ	Equalization tank
EQA	Environmental Quality Act 1974
F/M	Food to microorganism
FTR	Field training report
GD1	Guidance Document on Design and Operation of IETS.
GD2	Guidance Document on Performance Monitoring of IETS.
HRT	Hydraulic retention time
IECS	Industrial effluent characterization study
IER	Industrial effluent Regulations 2009
IETS	Industrial effluent treatment system

ISO	International standard organization
L/W	Length to width
MBR	Membrane bioreactor
MDMR	Monthly discharge monitoring report
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
NRCEP	National Registry of Certified Environmental Professionals
OD	Oxidation ditch
ODAS	Oxidation ditch activated sludge
OP	Oxidation pond
ORP	Oxidation reduction potential
OUR	Oxygen uptake rate
O&G	Oil and grease
O&M	Operation and maintenance
PAH	Polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	Physical-chemical process
PF	Plug flow
PMC	Performance monitoring committee
POAS	Pure oxygen activated sludge
RAS	Return activated sludge
RBC	Rotating biological contactor
SBR	Sequencing or sequential activated sludge
SFAS	Step feed activated sludge
SI	Solids inventory
SIER	Sewage and Industrial Effluents Regulations 1979
SOUR	Specific oxygen uptake rate
SS	Suspended solids
SSV	Settled sludge volume
SVI	Sludge volume index
TAAS	Tapered aeration activated sludge
TF	Trickling filter
TOC	Total organic carbon
UASB	Upflow anaerobic sludge blanket

USEPA	United States Environmental Protection Agency
VFA	Volatile fatty acids
VFD	Variable frequency drive
VSS	Volatile suspended solids
WAS	Waste activated sludge
ZSV	Zone settling velocity

THE PURPOSE OF THE GUIDANCE DOCUMENT

Industrial effluent engineering deals with the **principles** and **technologies** for the treatment of industrial effluents. Industrial effluent treatment systems (IETSs) are invariably part and parcel of any industrial manufacturing facilities which involves wet processing and wet manufacturing processes. As a consequence, it goes without saying, the inspectors of the Department of Environment need to be very conversant with the fundamental principles of the various types of **unit operations** and **unit processes**, whether they are classified as biological or physical-chemical treatment processes. These are the processes which they need to inspect on a daily basis whether for the purpose of verifying the information in the Notification package or for the objective of conducting industry inspections or for pollution complaint investigations. This Guidance Document has been prepared for the following purposes:

(i) To serve as an easy to use **practical resource guide** for the DOE inspectors in carrying out their duties related to the enforcement of the IER

(ii) To present the **fundamental working principles** of typical biological treatment processes (BPs) and physical chemical treatment processes (PCPs) commonly employed by the industries in Malaysia

(iii) To provide a comprehensive discussion of the **performance monitoring** (PM) elements of all BPs and PCPs typically encountered by DOE inspectors on their inspection duties

(iv) To cultivate among DOE inspectors a culture of **affinity for technical knowledge** hence as a consequence, it will improve their image as staff with high technical competence

The knowledge contained in the Guidance Document is essential to provide a firm foundation necessary for **effective enforcement** of the Industrial Effluent Regulations 2009.

INTRODUCTION TO IETS PERFORMANCE MONITORING AND THE CERTIFICATION PROGRAMS

Industrial effluent treatment systems (IETSs) can range from simple unit operations that require only cursory attention to specialized, highly complex unit processes that demand the expertise and presence of specially trained, skilled individuals in order to provide optimum treatment on a continual basis. **Process control monitoring**, popularly known as **performance monitoring** in Malaysia, is the primary tool utilized by IETS operators/ supervisors to monitor and evaluate the performance of the various unit operations and unit processes in the IETS. This monitoring includes, but is not limited to, the collection of samples for analysis, the use of **in situ** or **on line** electronic monitoring devices. The information gathered and its subsequent **interpretation** provides the basis for judging whether the treatment processes are occurring optimally. Based on the information, appropriate adjustments to the **operational parameters** of the IETS can then be made by the IETS operator/supervisor to maintain the IETS in the optimal range suited for his industrial effluent.

The success of the operation of an IETS is primarily in the hands of the **operator/ supervisor.** A knowledgeable and skilled operator/supervisor knows how to **monitor** the processes occurring in his IETS, understands what **factors** affect the IETS performance, knows what **operational conditions** are best for his IETS and how to **maintain** them, knows how to respond to **upset conditions**, understands the **social obligations** and **legal implications** for **noncompliance**.

Successful operation of an IETS is an integral part of the operation of a successful industry. A trained and skilled IETS operator/supervisor is not anymore a luxury but rather a must-have to the industry to ensure **continuous regulatory compliance**. **Good environmental performance** not only portray **positive corporate image**, but avoid possibility of factory downtime and hefty monetary penalties due to **legal actions** from the environmental authority. The industries must pay great attention to the training of their staff in the **proper operation and maintenance** of the IETS.

The DOE introduced the CePIETSO certification program for the **industry personnel** to mainstream the IETS agenda in the industrial sector. The program integrates several

new elements in industrial water pollution control including requirement on performance monitoring, record keeping, competent person and self reporting.

The practice of IETS performance monitoring introduced by the DOE in 2006 and currently being enforced through the Industrial Effluent Regulations 2009, which is taught in the CePIETSO course will cultivate a **positive culture** within the industry where the underpinning principles/drivers of **self regulation**, social accountability, "beyond compliance", "informed decision making", etc. are practiced. The culture will help **mainstream** IETS performance issues into the **day to day management** of the industry, as the case is in developed countries, paving the way for **excellence** in environmental regulatory compliance.

The industries' responsibility is to ensure **proper operation and functioning** of their IETSs and regulatory compliance on a continuous basis. On the other hand, the DOE's mandated responsibility is to ensure the industries are discharging this responsibility in a satisfactory fashion. While the industries' perspective is from the **operational aspects**, the DOE's perspective is from the **inspectional aspects**. Both aspects warrant sufficient **knowledge** (minds on) and **skills** (hands on) to assure the IETSs are operated, maintained, monitored and inspected in a systematic and technically sound manner.

The CePIETSI certification course is a **mirror image** course for the DOE officers designed to develop expertise within the DOE at the same level as the industry personnel. The CePIETSO course focuses on the operational aspects while the CePIETSI course on inspectional aspects of the IETS. Both courses are rated to be **equivalent in status** and represent two sides of a coin. Competent personnel on both sides of the coin complement each other to discharge their own responsibilities from different perspectives. CePIETSOs and CePIETSIs mutually support each other to produce the desired deliverable, that is, **compliant effluents on a continuous basis and mainstreaming of IETS agenda in the industrial sector**.

CHAPTER 1:

WHAT IS EFFLUENT ENGINEERING?





CHAPTER 1:

WHAT IS EFFLUENT ENGINEERING?

1.1 Environmental and wastewater engineering chemistry

Over the last decade, a specialized branch of chemistry, loosely described as **wastewater engineering chemistry** has evolved within the wider fold of environmental engineering chemistry. Wastewater engineering chemistry as applied to the treatment of **industrial effluents** (which is referred to as **industrial effluent engineering chemistry** in this document) deals with a broad spectrum of subject matter including the effluent's unique **characteristics**, the **impacts** of its discharge into the environment and the fundamentals of **treatment technologies** applicable for treating the myriad of contaminants contained in the effluent. The **physical and chemical principles** governing the treatment processes are also an integral part of the coverage of industrial effluent engineering chemistry. A firm grasp of the principles and mechanisms involved in wastewater engineering chemistry is a prerequisite for a thorough understanding of the wide scope of issues relevant to the field of **industrial effluent treatment** and consequently for finding successful solutions to them. A working understanding of the various aspects mentioned above is imperative and a great asset to the DOE officers who have been entrusted the task to institute and implement industrial water pollution control programs including enforcement on industrial premises.

1.2 Why study industrial effluent engineering chemistry?

The solution to environmental engineering problems often demands the use of a variety of techniques and devices used by the engineers, chemists, physicists and biologists. This is usually beyond the scope of most college courses in quantitative chemistry. Specialized courses described as "environmental chemistry" or "wastewater analysis" have been developed to cater for these needs. The study of the engineering chemistry of industrial effluents elucidates the **characteristics**

of the effluents, discusses the **microbiological processes** that can be utilized to treat them, unravels the **fundamental mechanisms** involved in physico-chemical treatment processes and establishes the technical rationale for conducting IETS performance monitoring. Understanding of these aspects of wastewater engineering would go a long way in establishing a solid foundation of **industrial water pollution control** for the DOE officers. A firm grasp of the subject matter would definitely boost confidence of the officers in discharging their duties in water pollution control work and enhance the quality of their decisions.

1.3 Industrial effluent engineering and DOE officers

Industrial effluent engineering chemistry lays the fundation for industrial effuent engineering (IEE). IEE is intimately connected with the major **areas of responsibilities** of the DOE, whether it is industrial water pollution control or scheduled waste management or environmental impact assessment. Some key decisions by a staff member of DOE which would have far reaching implications are influenced by his understanding of industrial effluent engineering. All DOE staff need to have a **working level of understanding** of industrial effluent engineering in order to discharge their duties satisfactorily. More advanced understanding of IEE is a prerequisite for those who aspire to be **subject matter experts** in IEE.

CHAPTER 2:

CHARACTERISTICS OF INDUSTRIAL EFFLUENTS AND DISCHARGE IMPACTS





CHAPTER 2:

CHARACTERISTICS OF INDUSTRIAL EFFLUENTS AND DISCHARGE IMPACTS

2.1 Characteristics of industrial effluents

Wastewaters are commonly categorized as **domestic wastewater** or **industrial wastewater**. In this course and also as commonly being referred to by the Department of Environment, industrial wastewaters are specifically referred to as **industrial effluents**. Domestic wastewater refers to wastewater generated from "non manufacturing activities" occurring in residential homes which includes **sewage** (from toilets) and **grey water** (from bathrooms and kitchens). Industrial effluents contain numerous substances that originate from the **raw materials** and the **processes** utilized by the industry to manufacture the products.

The characteristics of the effluent are usually defined in terms of their **physical, chemical and bacteriological parameters**. Physical parameters include temperature, suspended solids, color, taste and odor. Chemical parameters include pH, metals, various organic chemicals such as phenols, refractory organics and nutrients which are nitrogen and phosphorus. Bacteriological parameters include microorganisms and pathogens.

An industrial effluent can be classified as an **organic effluent** or **inorganic effluent** based on contaminants it contains. The contaminants can also be categorized as **organic** or **inorganic substances.** Organic substances are compounds made up of **carbon** which may contain a combination of other elements such as hydrogen, oxygen, nitrogen, sulfur and other trace elements. Some organic compounds such as proteins, carbohydrates, and fats are easily degraded by microorganisms (**biodegradable**) while others are more stable and cannot be easily broken down by microorganisms (**non biodegradable-refractory**)). The latter are particularly true with many **synthetic organic compounds** developed for agriculture and industry such as pesticides, herbicides, dyes, pigments, chlorinated compounds,

etc. Animal fat, vegetable and petroleum oils are collectively referred to as **oil and grease** are also not quickly broken down by bacteria. Industrial discharges may also contain **metals** originating from various manufacturing processes utilized in industries such as metal finishing, rubber glove production, semi conductor manufacture, photographic shops, etc. These metals include arsenic, cadmium, chromium, copper, lead, mercury, zinc, silver, etc.

Industrial effluents are also characterized by their **oxygen demand**. The two most widely used tests for oxygen demand are **biochemical oxygen demand** and **chemical oxygen demand**.

Industrial effluents may also contain solids which can consist of **organic** or **inorganic materials**. Solids can be categorized as **settleable solids** (such as sand, grit, and heavier organic and inorganic materials), or **suspended solids** (such as colloidal materials that resist settling and may remain suspended in the effluent) or **dissolved solids** (such as salt).

Table 2.1 gives a guide on significant pollution parameters for some common industry categories/types.

Table 2.1: Priority effluent parameters for different industries*

Industry Type	Typical Priority Effluent Parameters
Chlor-Alkali (Mercury Cell)	T, pH, SS, Mercury, Chlorides
Chlor-Alkali (Diaphragm Cell)	T, pH, SS, Chlorides
Metal Finishing and Electroplating	T, pH, SS, O&G, Arsenic, Cadmium, Chromium (trivalent), Chromium (hexavalent), Lead, Nickel, Mercury, Silver, Zinc, Fluoride, Cyanides-depending on the metals involved
Fertilizer (Nitrogenous)	T, pH, COD, SS, AN
Fertilizer (Phosphate)	T, pH, COD, SS, AN, Fluoride

Pulp and Paper	T, pH, BOD_5. COD, SS, Sulfides,
Petroleum Refining	T, pH, COD, SS, BOD_5, O&G, Phenolic compounds
Steel Industry	T, pH, COD, SS, Chromium (trivalent), Iron, Cadmium, Copper, O&G, Fluoride
Synthetic Fiber	T, pH, BOD_5, COD, SS, Sulfides, O&G
Tanning and Leather Finishing	T, pH, BOD_5, COD, SS, Sulfide, Chromium (trivalent), Chromium (hexavalent), Phenolic compounds, O&G,
Textile Processing	T, pH, BOD_5, COD, SS, Chromium, Copper, Color
Pigments and Dyes	T, pH, COD, Lead, Copper, Zinc
Thermal Power Plants	T, pH, SS, O&G
Rubber Products	BOD_5, COD, SS, Zinc, Chromium,
Paints, Varnishes & Lacquers	pH, COD, SS, Lead, Chromium, Cadmium, Zinc, Barium
Pesticides	pH, COD, Mercury
Printing	COD, Lead, Color
Industrial Chemicals	pH, BOD_5, COD, SS Phenolic Compounds, Cyanide, AN, Cadmium, Lead, Chromium, Mercury, Nickel, Zinc, Arsenic
Oil & Gas Production	T, pH, BOD_5, COD, SS, O&G, Chloride, Phenolic Compounds, AN, Fluorides, Barium, Boron, Formaldehyde
Petrochemicals	T, pH, BOD_5, COD, SS, O&G, Phenolic Compounds
Dairy Industry	T, pH, BOD_5, COD, SS, O&G
Fruit and Vegetable Processing	T, pH, BOD_5, COD, SS
Food and Beverage	T, pH, BOD_5, COD, SS, O&G
Glass Manufacturing	T, pH, COD, SS, Barium, O&G

Sugar	T, pH, BOD_5, COD, SS, O&G
Detergent	pH, COD, O&G, Anionic Detergent
Photographic	pH, COD, Silver, Cyanide, Fluoride
Glue Manufacture	pH, BOD_5, COD, Phenolic compounds; Formaldehyde
Oil & Gas Exploration	T, pH, BOD_5, COD, SS, O&G, Chloride, Phenolic compounds, Boron, Fluoride, AN
Vegetable Oil Mills	T, pH, BOD_5, COD, SS, O&G
Plastic Materials and Products	SS, endocrine disruptors,
Wood Products	pH, SS, COD, Phenolic compounds
Pharmaceutical	T, pH, BOD_5, COD, SS
Solar panel	T, pH, COD, Fluoride, AN

Note: * list and parameters not exhaustive
BOD = biochemical oxygen demand; COD = chemical oxygen demand,
SS= suspended solids; O&G = oil and grease
AN = ammoniacal nitrogen

2.2 Effects of effluent discharges

Organic matter contained in the effluents when discharged into a watercourse will undergo **biodegradation** by the action of microorganisms. In the biodegradation process the microorganisms will utilize the **dissolved oxygen** resources in the waterbody. This can reduce or deplete the supply of oxygen in the water needed by aquatic life which may lead to occurrence of **fish kills**. **Suspended solids** may settle out top the bottom of the river resulting in **sludge build up**. When decomposed, **sludge oxygen demand** will be exerted on the river which may also cause **oxygen depletion** and **generation of odors**. High concentration of suspended solids effects **disinfection effectiveness** because pathogenic organisms may be shielded from the disinfectant by the suspended solids.

Some toxic **refractory organics** (difficult to biodegrade) such as polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) (which were once used in electrical transformers) and various agricultural chemicals (such as herbicides and insecticides) may cause **bioaccumulation** in body tissues and affect the food chain. Several refractory organics are **carcinogens** (cancer inducing), such as hydrazines, aromatic amines, aromatic hydrocarbons, organohalogen compounds and alkylating agents (ethers, sulfonates, alkenes and alkynes).

Some **metals** even at low concentration may be **toxic** to aquatic life and their presence in a watercourse may render the watercourse **unsuitable** for a source of public water supply.

When large amounts of **oil and grease** are discharged to a receiving watercourse they may float to the surface and harden, causing **aesthetically** unpleasing conditions. The floating oil and grease decreases the **oxygen transfer efficiency** of water courses causing septic condition.

Discharge of industrial effluents containing abundance of nutrients (nitrogen and phosphorus) can lead to eutrophication of enclosed water bodies such as lakes and bays. Algal blooms may occur due to enhanced phytoplankton growth which will use up the dissolved oxygen in the water resulting in the death of aquatic organisms. The algal bloom may also **block sunlight** affecting photosynthetic activities of marine plants. Some algae produce **toxins** that are harmful to higher forms of life causing problems along the **food chain** and affect any animal that feeds on them.

Some industries discharge **ammonia** in their effluents. The term ammonia refers to two chemical species which exist in equilibrium in water, namely NH_3, which is the **un-ionized** form and NH_4^+, which is the **ionized form.** Typically, tests for ammonia measure **total ammonia** (NH_3 plus NH_4^+). However, from the **toxicity** viewpoint only the un-ionized form (NH_3) is **toxic** to fish as opposed to the ionized form (NH_4^+). In general, more NH_3, hence greater toxicity exists at higher pH. This toxicity begins at an **ambient concentration** of NH_3 as low as 0.05 mg/L

Industrial effluents, unlike sewage, seldom contain **pathogens** such as salmonella, cholera or E. coli which are of concern from health viewpoint.

2.3 From the perspective of the DOE officer/inspector

From this chapter, as a DOE officer/inspector you understand that:

(i) An industrial effluent (**organic** or inorganic **effluent**) can have different impacts on the environment based on what kinds of **contaminants** are found in it

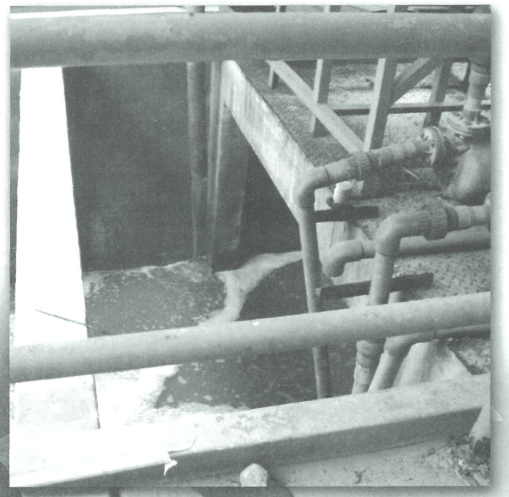
(ii) Some organic contaminants are **biodegradable** hence its discharge may result in oxygen depletion while some are **non biodegradable** whose discharge will not be detrimental from oxygen depletion viewpoint. However, some refractory organics may cause adverse environmental impacts due to their harmful characteristics.

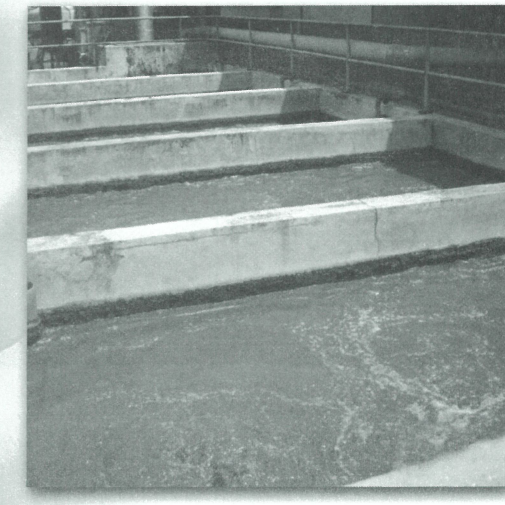
(iii) Inorganic contaminants are usually **toxic** to aquatic life even at low concentrations

(iv) Effluent **discharge standards** re imposed to minimize the adverse impacts from effluent discharges.

CHAPTER 3:

OVERVIEW OF INDUSTRIAL EFFLUENT TREATMENT SYSTEMS (IETSs)





CHAPTER 3:

OVERVIEW OF INDUSTRIAL EFFLUENT TREATMENT SYSTEMS (IETS)

3.1 Overview of industrial effluent treatment systems

The treatment methods/technologies selected for a particular effluent would normally consist of a **combination of a number of unit operations and unit processes** depending on several factors such as:

(i) The characteristics of the effluent
(ii) Degree of treatment required
(iii) Effluent standards imposed
(iv) Capital and operating cost
(v) Space availability
(vi) Manpower requirement.

An example of a general **flowchart** showing typical unit operations and unit processes used to treat an industrial effluent is shown in Fig 3.1 below.

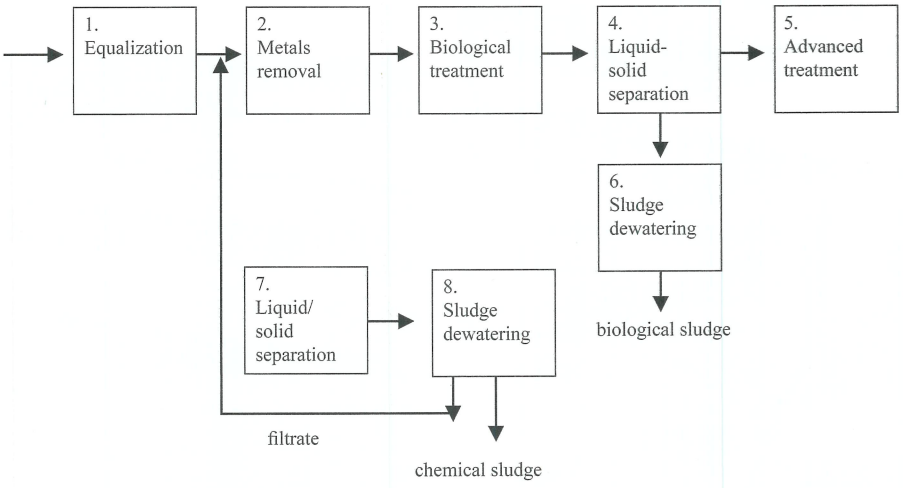


Fig. 3.1 : Flowchart of a typical IETS

Processes 1, 2, 4, 5, 6, 7 and 8 are typically **physical chemical processes** employed to remove **solids**, **nonbiodegradable organics** and **metals,** while process 3 is **a biological process** utilized for the removal of **dissolved biodegradable** organics.

An industrial effluent may contain a **cocktail of contaminants** which require different technologies to treat the contaminants. Table 3.1 summarizes different treatment technologies/processes commonly being utilized for treating different categories of contaminants.

3.2 Technology selection matrix

An IETS is typically comprised of several treatment processes termed as **unit operations** or **unit processes**. Unit operations refer to treatment processes utilizing **physical processes** to remove the pollutants while unit processes employ **chemical** or **microbiological** reactions to remove the contaminants. Table 3.1 below shows the types of treatment processes available for the treatment of different types of pollutants.

Table 3.1: Treatment technology selection matrix

Type of Pollutant	Type of Treatment Process
a) Degradable organics (reflected in BOD level)	Biological treatment - Stabilization ponds - Aerated lagoons - Trickling filters (TFs) - Rotating biological contactors (RBCs) - Activated sludge (AS) - Anaerobic treatment
b) Volatile organics	Biological treatment Air or steam stripping Carbon adsorption Chemical oxidation

c) Refractory toxic organics (reflected in COD level)	Carbon adsorption Chemical oxidation Anaerobic treatment Wet air oxidation
d) Suspended solids	Sedimentation Flotation Filtration Membrane processes
e) Oil and grease	Gravity separation - Oil trap - Corrugated plate interceptor (CPI) - American Petroleum Institute (API) separator Flotation
f) Metals	Chemical precipitation Ion exchange
g) Nutrients-Nitrogen	Steam stripping Biological treatment - Nitrification & denitrification
h) Nutrients-Phosphorus	Chemical precipitation Biological treatment
i) Color	Carbon adsorption Chemical oxidation

3.3 Treatment classification

IETS processes can also be broadly classified as **primary, secondary** or **tertiary** treatment processes. Primary treatment may utilize **physical and/or chemical processes** to prepare the effluent for the next stage of treatment that is **biological treatment processes**. Tertiary treatment using **chemical or/and physical processes** is normally warranted to further polish the treated effluent to comply with more stringent discharge standards.

It is to be noted that there is **no hard and fast rule** about the classification of treatment processes (as primary or tertiary), but what has been described above is commonly being used in practice. In certain situation, a treatment process which is usually classified as a tertiary/advanced treatment process in domestic wastewater treatment may be categorized as a primary treatment process in industrial effluent treatment scenario. For example, if an industrial effluent contains both biodegradable organic materials and metals, the metals have to be removed (for example via a chemical precipitation process) prior to subjecting the effluent to a biological treatment process (for example via an activated sludge process). In this case, the chemical precipitation step is considered to be a primary treatment process. In the treatment of domestic wastewater a metal removal process (e.g. an ion exchange process) may be utilized to remove trace amounts of metal as a polishing step hence the process is regarded as tertiary/advanced treatment process rather than a primary treatment process.

Table 3.2 shows the treatment processes categorized according to the three classifications of primary, secondary and tertiary processes as applied to the treatment of industrial effluents.

Table 3.2: Classification of effluent treatment processes

Classification of Treatment	Treatment Process
Primary (preliminary, pretreatment)	Equalization Neutralization Flotation Sedimentation Coagulation/flocculation Chemical precipitation Ion exchange Filtration Air stripping

Secondary (Biological treatment)	Biological oxidation - activated sludge (AS) - trickling filter (TF) - rotating biological contactor (RBC) - oxidation pond (OP) - aerated lagoon (AL) - upflow anaerobic sludge blanket (UASB)
Tertiary (Advanced treatment)	Adsorption Ion exchange Biological nitrogen removal Chemical precipitation for phosphorus removal Media filtration Membrane processes Chemical oxidation

3.4 The interdependence between different IETS treatment components

In order to produce **compliant effluent** on a sustained basis, all the unit operations and unit processes within the IETS must be in the state of **optimal working conditions.**

3.5 From the perspective of the DOE officers/ inspector

From this chapter, as a DOE officer/ inspector you understand that:

(i) **Different technologies** are available for treating various pollutants commonly found in industrial effluents.

(ii) Each of the various unit operations and unit processes which makes up the entire IETS needs to work in unison to produce a **compliant final effluent** on a sustained basis.

(iii) IETS can be **upgraded** to benefit from the results of **research and experience** worldwide as well as to comply with new **regulatory requirements**.

CHAPTER 4:

RATIONALE FOR CONDUCTING PERFORMANCE MONITORING OF TREATMENT PROCESSES



MODULE 4:

RATIONALE FOR CONDUCTING PERFORMANCE MONITORING OF TREATMENT PROCESSES

4.1 Environmental pollution control through self regulatory approach

Self regulation is now the preferred approach to the control of environmental pollution adopted by many environmental agencies worldwide. From the perspective of Industrial Effluent Regulations (IER), self regulation approach translates into several regulatory provisions such as the provisions on **notification, competent person, performance monitoring, record keeping**, etc. Other related requirement includes the setting up of performance monitoring committee. From the perspective of the government, the arguments for self regulation are many; among them are:

(i) The staff strength of environmental agencies cannot keep up with the ever **increasing** number of industrial premises
(ii) Self regulation brings down the **cost of enforcement** to the government
(iii) Self regulation approach **develops internal commitment and skills** in the industrial sector, hence regulatory compliance is self ensured
(iv) Self regulation leads towards increased compliance which in turn improves industries' image resulting in better access of our products to **international market**.

4.2 Mainstreaming of IETS agenda and cultivation of a culture of self regulation

The central theme that pervades throughout the IER and the certification program is performance monitoring (PM) of the IETS. PM has a final destination with **three stops** along the way, reflected by their corresponding checkpoints. Stop one is the immediate checkpoint with the "**continuous compliance**" as the milestone. Stop two has the "**incorporation of IETS agenda into the factory management**" as its milestone. Stop three is the final destination which is characterized by the "**culture of self regulation and pride of environmental excellence**" as the

climax. Stop three will be reached only with the compounded efforts from other certification programs such as Certified Environmental Professional in Scheduled Waste Management (CePSWaM), ISO 1400 Certification, etc.

4.3 Legal requirements on IETS performance monitoring

IETS performance monitoring requirement which has become a legal requirement in the Industrial Effluent Regulations 2009 (IER) will ensure that the IETS components are closely monitored in a **systematic manner** and on a **scheduled basis**. Coupled with IETS **preventive and corrective hardware maintenance** program, this will in turn help guarantee IETS compliance with the discharge standards on a **continuous basis.** This is the tangible **outcome** of the performance monitoring program. Continuous regulatory compliance is only one benefit, albeit an important one, but performance monitoring program affords more than just that. By understanding the processes involved in the IETS and being able to control them, performance monitoring inculcates a **sense of ownership** in those who are involved in the IETS operation and supervision. **Self regulation** which is the preferred approach that is currently widely adopted by many environmental protection agencies (EPAs) worldwide will be cultivated through the performance monitoring procedure.

Additionally, the program puts the IETS compliance status in the center stage of the industry's **management procedure and decision making process.** Important decision such as whether to embark on factory expansion and increase production is dependent on the current status of IETS compliance. Performance monitoring is a **win-win concept** when incorporated into the industry's decision making process not only helps ensure continuous regulatory compliance on a sustained basis, but improves the industry's **corporate image** in the eyes of the public. This is a **good business strategy** which at the same time results in **improvement in water quality**.

4.4 Rationale for conducting IETS performance monitoring

Performance monitoring of an IETS is the **proactive and preventive monitoring** of all the major **IETS components** to ensure that each component is working properly and optimally as designed. Preventive monitoring and enforcement is practiced in many different fields such as health, occupational safety and road safety. Built in the monitoring procedure are corrective follow-up actions to be taken to address noncompliance situations. IETS performance monitoring which was introduced as a requirement in Malaysia since 2006 has been proven to be a powerful instrument for ensuring **effective IETS process control** resulting in maintaining **regulatory discharge compliance** on a continuous basis. IETS performance monitoring requires one to monitor some relevant parameters characteristic of the **unit process** or **unit operation** of the IETS on a scheduled basis. Performance monitoring concentrates on the processes in the IETS itself not on the IETS final effluent hence can be viewed as an **"upstream" activity** as opposed to compliance monitoring, which is a **"downstream" activity**. Performance monitoring is not the monitoring of the final effluent as misunderstood by some industries. Focusing only on the **final effluent** may lead to a **"too-late" situation** where things have gone out of hand and consequently are difficult to control or get back on track. The differences between compliance monitoring and performance monitoring are summarized in Table 4.1 while the benefits of performance monitoring are summarized in Table 4.2.

Table 4.1: Differences between compliance monitoring and performance monitoring

Compliance Monitoring	Performance Monitoring
Downstream activity	Upstream activity
Product focused	Ingredients focused
Result focused	Processes focused
"too late" information	"early warning" information
Processes not in control	In control of processes

Table 4.2: Benefits of performance monitoring

Benefits of performance monitoring
(a) Ensures that IETS components are in optimum operation at all times;
(b) Helps prevent IETS failure, hence avoid costly IETS recovery work;
(c) Helps to maintain continued compliance, hence improve corporate image and avoid embarrassing enforcement action;
(d) Maintains record of IETS performance which facilitates optimization of IETS and analysis of performance.

4.5 Guidance document on performance monitoring of industrial effluent treatment systems

The primary reference for the procedure to conduct IETS performance monitoring is the guidance document published by the DOE entitled **Guidance Document on Performance Monitoring of Industrial Effluent Treatment Systems.** The minimum specifications on IETS performance monitoring and record keeping requirements stipulated in the document must be adhered to by the industries.

4.6 From the perspective of the DOE officer/ inspector

As a DOE officer/ inspector, you understand that:

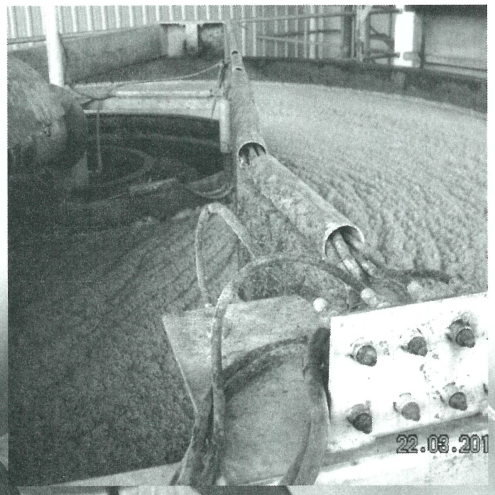
(i) There are strong compelling reasons for shifting the enforcement approach from one based purely on **factory inspections** by the DOE inspectors to self regulation based on **performance monitoring** conducted by the factory staff themselves.

(ii) IETS performance monitoring affords many **advantages and benefits** to the environmental agency as well as to the industries

(iii) Minimum requirements on IETS performance monitoring which need to be complied with by the industries are specified in the **Guidance Document on Performance Monitoring of Industrial Effluent Treatment Systems.**

CHAPTER 5:

OVERVIEW OF BIOLOGICAL TREATMENT PROCESSES





CHAPTER 5:

OVERVIEW OF BIOLOGICAL TREATMENT PROCESSES

This chapter is dedicated to the discussion of the **basic concepts** of the following biological treatment processes (BP) commonly employed for the treatment of industrial effluents:

Suspended growth systems

- Activated sludge process and its variants
  - Conventional activated sludge (CAS)
  - Extended aeration activated sludge (EAAS)
  - Sequencing batch reactor (SBR)
  - Membrane bioreactor (MBR)

Attached growth systems

- Trickling filter (TF)
- Rotating biological contactor (RBC)

Anaerobic process

- Upflow anaerobic sludge blanket (UASB)

Ponding systems

- Aerobic ponds
- Facultative ponds
- Maturation ponds

5.1 Biological treatment processes

Biological treatment processes are categorized as **secondary treatment** processes designed to remove **dissolved organic matter** from industrial effluents. In biological treatment, **microorganisms** are employed to utilize the organic matter, represented as BOD or COD contained in the effluent as their **food** supply. In the

biodegradation process the organic matter is oxidized and new cells are produced. In the presence of **oxygen,** other products of the process include **carbon dioxide** and **water,** while in the **absence of oxygen, methane** is produced. Typically, biological treatment is accomplished via three different processes and designs of the treatment system, namely: **attached growth** or **fixed film, suspended growth** and **pond systems**.

5.1.1 Attached growth systems

In attached growth processes microorganisms grow on **solid media** such as rocks, wood or plastic. The industrial effluent is distributed over the media where it flows past the film of microorganisms which is attached to the media. The **slime layer** of microorganisms on the media absorbs the **organic matter** and **nutrients** from the effluent and the film grows and gains in thickness. Sloughs of slime layer may get detached from the media and fall off. Examples of attached growth systems include the **trickling filter (TF)** and **rotating biological contactor (RBC).**

5.1.2 Suspended growth systems

In suspended growth systems microorganisms are kept in suspension in the effluent via the action of **mixing** and **aeration**. Aeration and mixing may be accomplished by the use of **mechanical aerators** (surface or submerged) or **diffused aeration systems**. As the microorganisms metabolize the organic matter from the effluent they grow in **size and number.** After the microorganisms have been kept in contact with the effluent for a predetermined time period (ranging from several hours to several months) they are separated from the liquid in a **clarifier** as sludge. Some of the sludge is **recycled back** to the aeration tank to maintain the desired concentration of microorganisms to continue to biodegrade the organic matter in the incoming effluent. The remainder sludge is **wasted** from the systems and undergoes subsequent treatment. Examples of

suspended growth systems are the activated sludge system and its variants such as **conventional activated sludge (CAS), extended aeration activated sludge (EAAS), sequential batch reactor (SBR), membrane bioreactor (MBR), oxidation ditch (OD), high-rate aeration, step aeration, contact stabilization, and pure-oxygen activated sludge.**

5.1.3 Ponding systems

Pond or lagoon systems are **shallow basins** which impound the industrial effluents for a relatively long period (**long retention time**) to allow for the **natural degradation** of the organic matter to take place. A **series of ponds** are used depending on the strength of the influent. In some cases where the influent is a high strength organic effluent (for example, palm oil mill effluent-POME) the first few ponds are naturally **anaerobic** (devoid of oxygen) due to insufficient supply of oxygen while the latter ponds are **facultative** (either absence or presence of oxygen) and **aerobic** (presence of oxygen). Pond systems for the treatment of industrial effluents are **not common** in Malaysia.

5.1.4 Aerobic systems

From the perspective of the way in which the microorganisms utilize oxygen, the IETS can be classified into **aerobic** (microorganisms require free molecular oxygen for their metabolism), **anaerobic** (microorganisms grow in absence of oxygen) and **facultative** (microorganisms can proliferate either in absence or presence of oxygen although using different metabolic processes). Under **aerobic** conditions, oxygen is the **electron acceptor**. The **microbial population** actively metabolizing the organic matter found in the industrial effluents is mixed, complex and interrelated. In a well-functioning IETS, apart from **bacteria** which are the main actors for the biodegradation of organic matter, **protozoas** and **rotifers** are usually present and are useful in consuming dispersed bacteria

or non-settling particles. The **biodegradation of organic matter** can be represented by a simplified equation as shown below:

$$\text{Cell + organic matter + oxygen} \rightarrow \text{more cells} + CO_2 + H_2O$$

Aerobic processes are characterized by:

- End products are primarily **carbon dioxide, water**, and **new microbial cell**
- Low **odor** production
- Many times **faster** than anaerobic decomposition
- Production of **large** amount of sludge

5.1.5 Anaerobic systems

Anaerobic systems are usually employed for the treatment of **high strength** organic effluents. The anaerobic bacteria thrive in the **absence of oxygen**. Under **anaerobic** conditions, there is no free dissolved oxygen (DO) or bound oxygen (e.g. NO_2^- or NO_3^-); hence, fundamentally a fermentation process takes place where there is low energy utilization and anaerobic bacteria grow very slowly. In an anaerobic process, proteins are broken down to ammonia (NH_3-N). Since DO oxygen is not present, NH_3-N cannot be oxidized to produce NO_2^-/NO_3^- hence it accumulates within the anaerobic system.

The anaerobic treatment undergoes **several phases** starting with **solubilization** of the organic matter present in the effluent. The solubilized organic matter in turn is converted to **volatile organic acids**, carbon dioxide and hydrogen by the **acid formers**. The process is known as **acidogenesis**. The acids are then consumed by **methane formers** to produce **methane** and **carbon dioxide**. The process is known as **methanogenesis.**

Anaerobic processes are characterized by:

- End products: **carbon dioxide, methane, and water**. Other products: **ammonia, hydrogen sulfide** (if sulfide/sulfate was present) and **mercaptans**
- **Low** sludge production

A version of anaerobic process which is gaining acceptance and popularity for treating industrial effluents in Malaysia is **upflow anaerobic sludge blanket** (UASB).

5.1.6 Anoxic systems

Anoxic systems, just like anaerobic systems are characterized by the **absence of free dissolved oxygen** from the system and presence of bound oxygen (e.g. NO_2^- or NO_3^-). Anoxic systems are typically utilized for the removal of **nitrogen** from domestic wastewater and industrial effluents where a two-step process is involved: the nitrification process and the denitrification process. In the first step, nitrogen present in the effluent is first converted to **nitrite** (by nitrosomonas) and then to **nitrate** (by nirobacter) in an **aerobic** treatment process, such as a **trickling filter** (an attached growth process) or an **activated sludge system** (a suspended growth process). In the second step, the nitrified effluent is then exposed to an environment **without free DO** (anoxic process) where nitrate will be used as an **electron acceptor** and converted to nitrogen gas (by denitrifiers). For efficient denitrification process to occur, a carbon source such as methanol is usually added to the anoxic reactor/zone.

5.1.7 Biological treatment systems used in Malaysia

In Malaysia, the most widely used biological treatment systems are the suspended growth systems (i.e. the **activated sludge system** and its modifications) and in limited application, the anaerobic system (particularly the **UASB**). This module concentrates only on those two systems.

5.2 Activated sludge system

The activated sludge process and its variants are the **most widely** used treatment process for treating domestic sewage as well as industrial effluents from a wide range of industries. The activated sludge process is very **versatile** and can be adapted to treat different characteristics of industrial effluent.

5.2.1 Flow regime

From the perspective of flow regime, activated sludge systems are categorized either as **a plug flow (PF)** or a **complete mix system (CMAS)** (See Fig. 5.1).

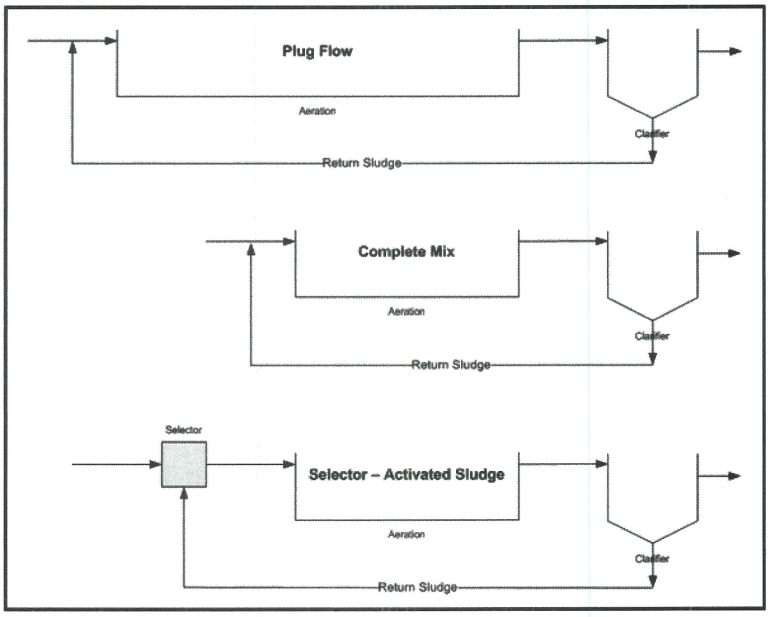


Fig 5.1: Different configurations of activated sludge system (Source: http://waterfacts.net/html/activated_sludge.html)

An aeration tank which is based on plug flow regime (PF) is typically designed as a **long narrow channel** through which the mixtures of raw effluent and return activated sludge (RAS) flow (top diagram in Fig 5.1).

On the other hand, in a complete mix system (CMAS), the aeration tank is conventionally **round, square**, or **rectangular** (middle diagram in Fig 5.1). Another modification to the AS is to add a **selector tank** ahead of the aeration tank (bottom diagram in Fig 5.1), to address **filamentous bulking**, a common problem associated with the operation of a CMAS. Selectors are small tanks in which the RAS and raw effluent is **pretreated** prior to its admission into the aeration tank. Typically the HRT in the selector tank is about 15 to 30 minutes.

The DO in the selector tank depends on its intended purpose and can be designed for **aerobic, anaerobic,** or **anoxic** conditions. An aerobic or anaerobic selector intended for preventing the growth of filamentous bacteria requires 2 to 3 mg/L and < 0.5 mg/L DO respectively. An anoxic selector is meant for **denitrification** purpose where treated secondary effluent is recycled to the selector tank to mix with the influent.

Table 5.1 gives a summary of typical characteristics, advantages and disadvantages of PFAS and CMAS.

Table 5.1: Characteristics, advantages and disadvantages of PFAS and CMAS

AS reactor type	Characteristics	Advantages and Disadvantages
Plug flow (PF)	Dimension L/W ratio > 5:1	Advantages (i) Smaller volume (ii) Greater volumetric loading (iii) More flexible operation (e.g. zone aeration, step feeding options, accommodates anoxic and aerobic processes for biological nutrient removal (iv) More efficient aeration (v) Reduced mixing requirement, per unit reactor volume (vi) Better settling characteristics (vii) More stable microbial population (viii) Inhibits filamentous bacteria growth Disadvantages (i) High oxygen demand in upstream (ii) High F/M ratio causes higher diffuser foulings in upstream (iii) Most suitable for low-strength effluents with minimal peak load variability (iv) Higher construction costs due to winding flow in baffled reactor.

Complete mix (CM)	Dimension L/W ratio > 5:1	Advantages (i) Allows good nitrification since COD is uniformly low (ii) Used in smaller systems, like package treatment system (iii) Tolerance of organic and toxic shock loads Disadvantages (i) Larger volume (ii) Higher aeration costs (iii) Less operational flexibility (iv) More prone to biomass instabilities like sludge bulking

5.2.2 Activated sludge system and its modifications

Throughout the years the conventional activated sludge system has been **modified** to improve its treatment capabilities to treat effluents with wide ranging characteristics and to achieve specific treatment objectives. The different **versions and modifications** to the activated sludge process include:

- Conventional activated sludge (CAS)
- Complete mix activated sludge (CMAS)
- Extended aeration activated sludge (EAAS)
- Sequencing batch reactors (SBR)
- Membrane bioreactor (MBR)
- Oxidation ditch activated sludge (ODAS)
- Contact stabilization activated sludge (CSAS)
- Pure oxygen activated sludge (POAS)
- Tapered aeration activated sludge (TAAS)
- Step feed/aeration activated sludge (SFAS)

In Malaysia, the most widely employed versions of the activated sludge system are the **CAS, CMAS, EAAS, and SBR**. Another version which is gaining popularity is the **MBR**. This section focuses its attention to the above five types of AS and its modified versions.

The CAS and CMAS have been described earlier. More discussion is dedicated to EAAS, SBR and MBR in the following paragraphs.

Extended Aeration Activated Sludge (EAAS)

The EEAS is the most common variation of the AS system that is capable of producing **high quality effluent** at reasonable operating and maintenance costs. The EAAS process operates with a relatively **low organic loading** (low F/M) and **long HRT, aeration time,** and **high sludge age**. The long HRT, aeration time and high sludge age means the process needs bigger aeration tank volume. EAAS generates **low production of sludge** since it operates in the **endogenous respiration** phase of the growth curve. Typical operational parameters of EAAS compared to those of CAS are summarized in Table 5.2.

Table 5.2: Typical operational parameters of EAAS and CAS (Source: USEPA, 1999)

Parameter	EAAS	CAS
F/M, kg BOD_5/kg of MLVSS. d	0.05 to 0.15	0.2 to 0.5
DO, mg/L	4 to 6	2 to 4
HRT, h	12 to 48	4 to 8
MLSS, mg/L	3000 to 6000	1500 to 3000
Sludge age, d	15 to 30	5 to 10

The air can be supplied either **mechanically** (e.g. by surface or submerged aerators) or by **diffusion** (i.e. by a submerged air diffusion system).

Sequencing Batch Reactor (SBR)

The SBR design is a **fill and draw** type of non-steady state activated sludge process where (**batch process**) all processes of equalization, aeration and clarification occur in one single tank. An SBR system does not need a separate clarifier. To optimize the performance of the SBR system, two or more reactors can be used in

a predetermined sequence of operations. The processes in an SBR occur in a **time sequence** as opposed to space sequence in a CAS. These steps can be altered for different operational applications.

The **five sequential steps** in SBR operation are namely:

(i) Fill-Fresh input of raw effluent into the reactor. Mixing or aeration can be adjusted to meet certain treatment objectives (for example, mixing and aeration-oxic: nitrification; mixing but no aeration-anoxic: denitrification)

(ii) React-Aeration of reactor content. Most BOD removal takes place in this phase. Some microorganisms will die because of the lack of food and will help reduce the volume of the settling sludge

(iii) Settle-Settling of sludge where there is no inflow or outflow of effluent to prevent turbulence of supernatant. Sludge settles as flocculent mass, forming a distinctive interface with the clear supernatant

(iv) Decant-Discharge of treated effluent to be carried out under quiescent conditions removal must be done without disturbing the settled sludge. A decanter is used to remove the clear supernatant effluent.

(v) Idle- A small amount of sludge is wasted and undergoes further treatment.

Major phases in the operation of the SBR are depicted in Fig 5.2. Table 5.3 is a summary of important design and operational characteristics of the SBR. The advantages and disadvantages of the SBR are summarized in Table 5. 4.

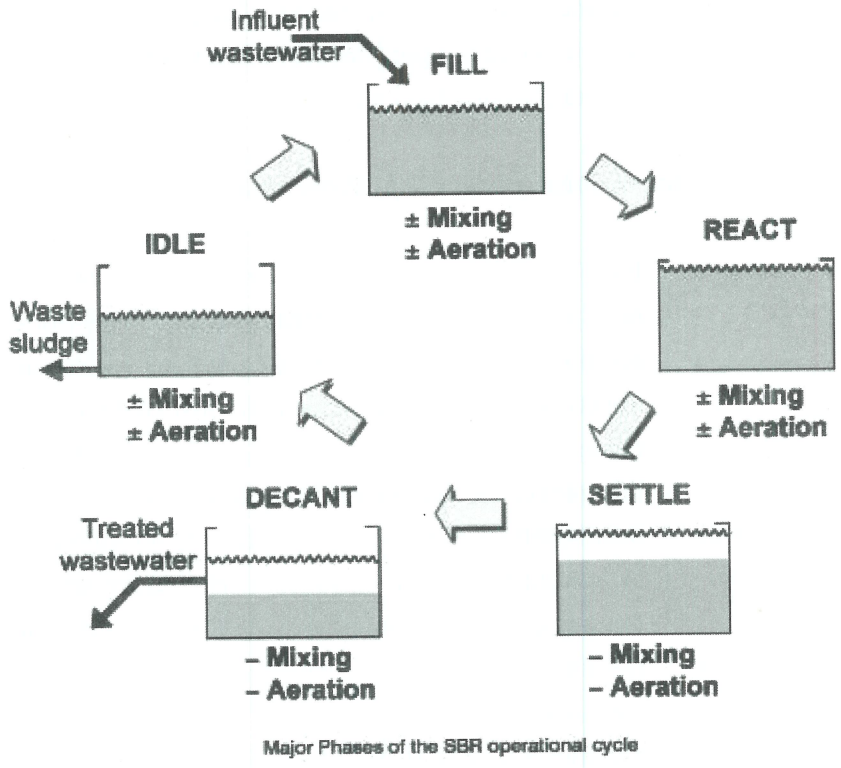


Fig 5.2: Major phases of the operation of the SBR (Source EPA, 2005)

Table 5.3: Key design and operational parameters for a SBR operating With conventional load (Source: AquaSBR Design Manual, 1995)

Parameter	Value
F/M, kg BOD_5/kg of MLSS.d	0.15 -0.6
Treatment cycle duration, h	4.0 - 24
Typically low water level MLSS, mg/L	2,000 - 4,000
HRT	Varies

Table 5.4: Advantages and disadvantages of SBRs (Source USEPA, 1999)

Advantages	Disadvantages
• Equalization, primary clarification, biological treatment, and secondary clarification can be achieved in a single reactor vessel. • Operating flexibility and control. • Minimal footprint. • Potential capital cost savings by eliminating clarifiers and other equipment.	• A higher level of sophistication is required especially for larger systems, of timing units and controls. • Higher level of maintenance associated with more sophisticated controls, automated switches, and automated valves. • Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations. • Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer. • Potential requirement for equalization after the SBR, depending on the downstream processes.

Membrane BioReactor (MBR)

The MBR is a combination of an **activated sludge process** characterized by a suspended growth of biomass, with a **membrane filtration system** designed to achieve an advanced level of **organic** and **suspended solids** removal. MBR technology produces **high quality effluent** which complies with stringent discharge standards or may even be **recycled** for direct reuse. Additionally, when designed accordingly, the MBR systems can also accomplish a high degree of **nutrient removal**.

In an MBR system, the membranes are **submerged** in the aeration tank of the AS system. Typically, the membranes have **porosities** ranging from 0.035 microns to 0.4 microns, which is generally considered to fall between micro and ultra filtration. At this level of filtration, a high quality effluent with extremely **low suspended solids** is produced which **does not require** subsequent sedimentation or filtration processes typically used in a CAS system. The elimination of the sedimentation or filtration process enables the MBR to be operated at a much **higher MLSS concentration**. Typically, MBR systems are operated with a MLSS concentration in the 1.0 to1.5% solids range (10,000 to 15,000 mg/L), which is 4 to 5 times that of a CAS system.

Although the MBR systems offer several distinct advantages over the CAS, EAAS, or SBR systems, the systems are **more expensive** to build and operate. The key advantages of MBRs are that they produce **better effluent quality** and are much more **resistant to upsets** due to fluctuating influent flows. In addition, if space is a constraint, the MBR system can be designed to have a much smaller footprint. Membranes used in MBR systems generally come in two types, namely: **hollow fiber membranes** and **plate membrane systems** which may be used internally within the aeration tank or as a separate unit after it. Fig 5.3 illustrates a schematic diagram of a submerged MBR with internal membrane filtration.

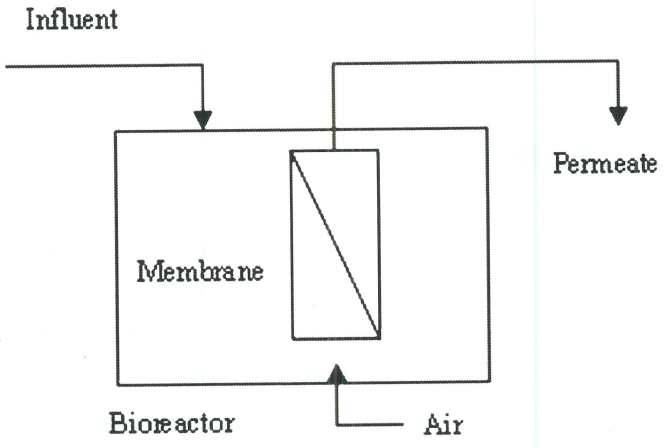


Fig 5.3: Submerged MBR with internal vacuum-driven membrane filtration (Source: Jelena Radjenovi´ et al, 2007)

The advantages and disadvantage of MBR technology are summarized in Table 5.5.

Table 5.5: Advantages and disadvantages of MBR technology

Advantages	Disadvantages
(i) No secondary clarifier required	(i) Very high aeration requirements
(ii) No RAS	(ii) Additional power requirement for vacuum on microfilter
(iii) Very good effluent quality (SS)	(iii) Requires dual aeration system for mixing and to prevent membrane fouling
(iv) Operates at high MLSS (5,000 to more than 20,000 mg/L)	(iv) Laborious and expensive membrane maintenance
(v) Operates at high sludge age (15-365 d)	(i) High capital costs for membrane system
(vi) Operates at low HRT (4-8 h)	
(vii) Small footprint (25% of CAS)	
(viii) Modular expandability	
(ix) Less susceptible to hydraulic shock loadings	
(x) Low sludge generation (20 to 40% less than CAS)	

5.3 Anaerobic systems

5.3.1 Upflow anaerobic sludge blanket (UASB)

Under anaerobic conditions, organic matter is degraded by microorganisms releasing **carbon dioxide** and **methane**. The anaerobic degradation process produces **less sludge** (10 to 15 percent sludge) compared to a conventional aerobic process. This is a substantial saving on sludge

disposal cost. Another cost saving comes from electricity usage because anaerobic process does not require aeration at all. Among the anaerobic processes, in Malaysia, the upflow anaerobic sludge blanket (normally termed as UASB) is gaining popularity for the treatment of industrial effluents. UASB is a form of **anaerobic digester** for effluent treatment. In the UASB process, the effluent to be treated enters at the bottom of the reactor and travels upwards through a blanket of suspended granular sludge which **biodegrades** and treats the effluent as it flows through it.

The sludge blanket comprises dense compact biofilms of **anaerobic microorganisms** referred to as "**microbial granules**" with diameters ranging from 0.5 to 2 mm. The blanket is kept in **suspension** due to the force of upward flow of the effluent and settling action of gravity. There is **no support media** in the UASB reactor, hence only those granule-forming microorganisms, capable of adhering to each other, survive and thrive.

As a result of the biodegradation of the organic compounds by the **anaerobic microorganisms** in the sludge blanket, **methane** and **carbon dioxide** are released. Mixing of the sludge is effected by the **rising gas bubbles** without the need for any mechanical mixing. Any suspended solids reaching the top of the reactor is deflected downwards by the **sloped walls**. The **treated effluent** is extracted from the top of the reactor in an area above the sloped walls. The gas that rises to the top is collected in a **gas collection dome** and can be used as an energy source, after **scrubbing**. An **upflow velocity** of 0.6 to 0.9 m/h must be maintained to keep the sludge blanket in suspension.

Depending on the strength of the raw effluent and the discharge standard imposed by the environmental authority, **post-treatment** of the effluent from the UASB system may be required.

A schematic diagram of a typical UASB reactor is shown in Fig 5.4. Table 5.6 summarizes the advantages and disadvantages of UASB system.

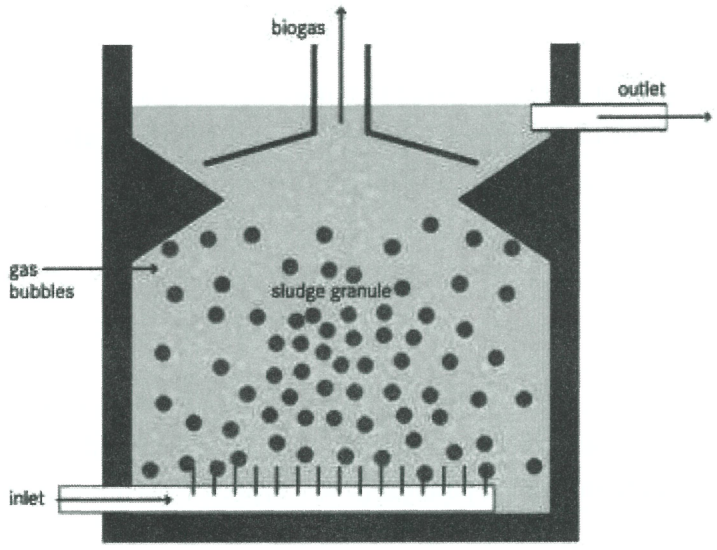


Fig 5.4: Cross-section of an upflow *anaerobic* sludge blanket (UASB) reactor (Source: Tillay et al., 2008)

Table 5.6: Advantages and disadvantages of UASB system

Advantages	Disadvantages/limitations
(i) High organics removal (85% to 90% of COD removal).	(i) Difficult to maintain optimum hydraulic conditions (upflow and settling rate must be balanced).
(ii) Can tolerate high organic loading rates (up to 10 kg BOD/m^3.d) and high hydraulic loading rates.	(ii) Long start up time (about 3 months)
(iii) Low sludge production (desludging required once in 2 to 3 years).	(iii) Treatment may be unstable with variable hydraulic and organic loads.
(iv) Biogas can be used as energy source	(iv) Constant source of electricity is required.
	(v) Not all parts and materials may be available locally.
	(vi) Requires expert design and construction supervision
	(vii) Requires trained operator and constant supervision

5.4 Attached growth systems

Attached growth systems or fixed film processes such as the trickling filters (TFs) and rotating biological contactors (RBCs) are **not commonly** being employed to treat either sewage or industrial effluents in Malaysia.

5.4.1 Trickling filters (TFs)

Trickling filters **(TFs)** are generally described as conventional **aerobic** biological effluent treatment systems where effluent is sprayed to **trickle** through a permeable bed made of gravel or plastic media. The microorganisms **attach** themselves to the media in the bed and form a biological film over it. As the effluent percolates through the media, the microorganisms consume and remove contaminants from the effluent. TFs are also known as **biofilters** or **biological filters** to emphasize that essentially the process responsible for treating the effluent is not filtration and mechanical straining of solids, but that the removal of organic substances occurs through microbial processes carried out by the microorganisms. A schematic diagram of a TF is illustrated in Fig 5.5.

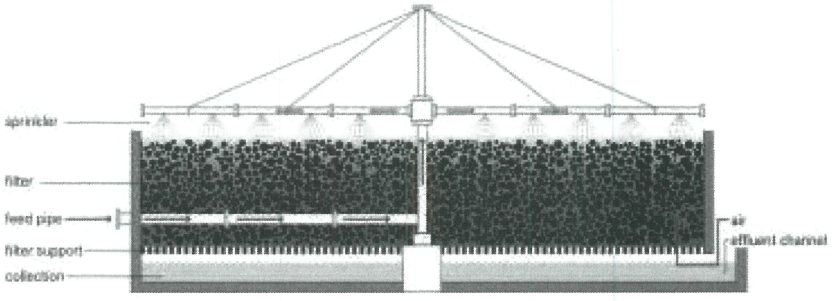


Fig 5.5: A schematic diagram of a trickling filter (Source: Tillay et al., 2008)

5.4.2 Rotating biological contactors (RBCs)

The basic process of a **rotating biological contactor** (RBC) is similar to that occurring in the trickling filter. The design of an RBC consists of a series of **circular disks** mounted side by side on a common shaft which is rotated through the effluent flow. The effluent is typically contained in a concrete tank where 40 % of the disks' surface area remains **submerged** in the effluent. As the disks rotate, oxygen is made available to the microorganisms which will biodegrade the organic constituents in the effluent and multiply. Over time a **biological slime** is developed on the disks. **Excess biomass** shears off at a steady rate and is then carried through the RBC system for removal in a **clarifier**.

Fig 5.6 shows a schematic diagram of an RBC.

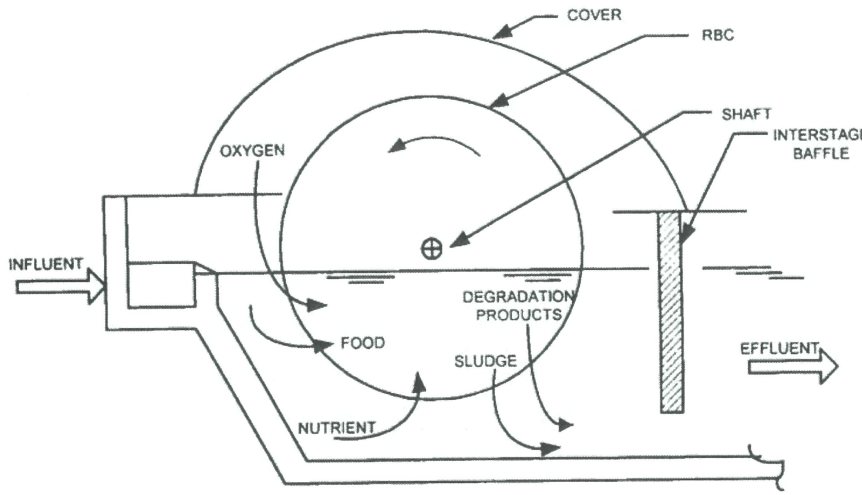


Fig 5.6: A schematic diagram of an RBC
(Source: Grady et al, 1999)

5.5 Ponding systems

Ponding systems are popular for the treatment of **high strength organic effluents** such as palm oil mill effluents (POME). However, treatment of industrial effluents by ponding systems is **not common** in Malaysia. Ponding systems come with different names, primarily depending on the nature of treatment processes occurring in the ponds or their intended purpose. Ponding systems are also commonly known as stabilization ponds. The types of ponding systems are briefly discussed below.

5.5.1 Anaerobic ponds

Anaerobic ponds are typically 2 m to 5 m deep and their primary function is to reduce the organic matter through microbial degradation process by the anaerobic microorganisms. They are loaded at a relatively high loading rate. The anaerobic process releases hydrogen sulfide (H_2S), carbon dioxide (CO_2), and methane (CH_4). A substantial **reduction of BOD** is achieved in anaerobic ponds.

5.5.2 Aerobic ponds

Aerobic ponds are large, **shallow lagoons** with a water depth of 0.2 m to 1.2 m. Oxygen for the aerobic bacteria is supplied by wind action and also produced by algae during photosynthesis. Oxygen is available throughout the entire depth of the ponds with varying concentrations.

Organic matter is broken down by the microorganisms and converted to chemical compounds (such as carbon dioxide, ammonia (NH_3), water (H_2O), phosphates (PO_4)) which are in turn used by the algae. Sometimes to increase treatment efficiency the pond contents are mechanically mixed on a periodic basis.

A significant amount of BOD_5 is **removed** in aerobic ponds.

5.5.3 Facultative ponds

Facultative ponds have **long detention time** which may run up to 50 to 60 days. The ponds are **deeper** than the aerobic ponds and typically possess **three distinct layers** (based on oxygen availability), namely: top layer which is aerobic; middle layer which is facultative, and bottom layer which is anaerobic. The microbial processes occurring in the three layers can be briefly described as follows.

(i) Top layer: **aerobic bacteria** consume organic matter releasing ammonia, carbon dioxide, water, etc. Algae use the carbon dioxide, ammonia and phosphates in photosynthesis and metabolic processes and release oxygen during photosynthesis.

(ii) Middle layer: the condition here fluctuates between aerobic and anaerobic conditions. **Facultative bacteria** thrive and oxidize organics in this zone where there is absence of or minimal amount of oxygen.

(iii) Bottom layer: settled solids are consumed and biodegraded by **anaerobic bacteria** which release hydrogen sulfide, carbon dioxide, and methane.

These ponds **reduce** a significant amount of BOD_5.

5.5.4 Maturation Ponds

Maturation ponds, also called **polishing ponds** are the ponds that are very **lightly loaded** with organics and usually receive effluent from a facultative pond. They are **shallow**, with **no distinct layers** and are well oxygenated and have detention times of **30 days** or more. The **algae population** of the maturation pond is much more diverse than that of facultative ponds. Maturation ponds do not remove any appreciable amount of BOD_5 but they play significant role in **nutrients removal** (phosphorus and nitrogen).

5.5.5 Symbiotic relationship between pond algae and bacteria

There exists a mutually beneficial **symbiotic relationship** between the pond algae and the pond bacteria: the algae provide the bacteria with oxygen from photosynthetic activities and the bacteria provide the algae with carbon dioxide from biodegradation process. This phenomenon is especially true in facultative ponds.

5.6 From the perspective of the DOE officer/ inspector

As a DOE officer/ inspector you:

(i) Understand that biological treatment processes (BPs) utilize **microbiological processes** to biodegrade organic matter, hence treat the effluent.

(ii) Understand that different BP systems utilize **different types of microorganisms** which biodegrade organic matter using different microbial processes, hence require different environmental conditions and produce different end products.

(iii) Understand that **optimum environmental conditions** must be maintained for favorable growth of the relevant types of microorganisms within the BP systems.

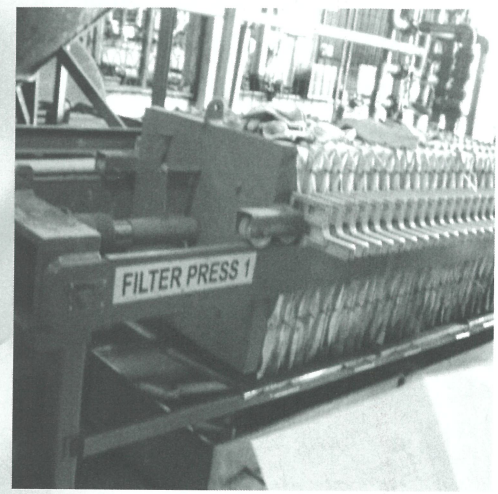
(iv) Could utilize the knowledge obtained from this chapter in the course of conducting **IETS inspections** and in solving environmental **pollution complaints**.

CHAPTER 6:

PERFORMANCE MONITORING OF COMMON BIOLOGICAL TREATMENT PROCESSES- THE WORKING CONCEPTS







CHAPTER 6:

PERFORMANCE MONITORING OF COMMON BIOLOGICAL TREATMENT PROCESSES- THE WORKING CONCEPTS

6.1 Successful operation of IETS

The success of operation of an IETS is reflected in the quality of the **final effluent**. As a DOE inspector, your primary concern and interest is to ensure that the effluent quality complies with the stipulated **discharge standards** all the time.

The quality of effluent achieved is dependent upon two broad categories of factors; those related to:

(i) The adequacy of the **design** of the IETS at the design stage, and
(ii) The **optimal IETS operational parameters** being maintained at the operational stage.

In any biological treatment process (BP) there are a number of factors that can affect overall **efficiency** of the process to remove the organic matter. The treatment efficiency is reflected in the **effluent BOD, COD** and **SS concentration**. Some factors fall under the responsibility of the **design engineers** and have been taken into consideration at the **design stage**. These include sizing and computing the dimensions of the following unit operations/processes: aeration tank, clarifier, equalization tank (EQ), return activated sludge (RAS), aeration supply, waste sludge handing, and sludge disposal. Once decided and fixed by the design engineer, these factors which invariably affect the major IETS structures/components cannot be changed. Other sub-factors affecting IETS efficiencies include fluctuations in daily effluent generation rate and effluent characteristics (e.g. BOD strength) which are related to the manufacturing process employed by the industry. Such factors also should have been incorporated in the design of the IETS at the design stage. All of the above factors are **not amenable to control** by the IETS supervisor/operator at the operational stage.

There are other factors affecting efficiency that are **within the control** of the IETS supervisor/operator. These include the food to microorganism (F/M) ratio, sludge age (θ_c), proper effluent flow equalization, return activated sludge rates, dissolved oxygen (DO) in aeration tanks and sludge disposal.

At the operational stage, as a DOE inspector, to ensure effective IETS operation, those factors which are within the control of the IETS supervisor/operator [those falling under the group (ii)] must be maintained within **optimal operating conditions**. Effective operation translates into better **final effluent quality** being maintained on a continuous basis.

6.1.1 The working concepts for monitoring the performance of biological treatment processes (BPs)

As discussed earlier in Chapter 5, there are various **processes, systems** and **technologies** within the broad category of biological treatment processes (BPs). Although fundamentally, the underlying principles may be similar, there exist differences between them which may require different operational factors to be maintained for their successful operation. Consequently, some factors may be more important to a certain BP while other factors are more important to other BPs.

For an engineered treatment system like an activated sludge process, the main objective of an IETS operator/supervisor is to be able to **control the process and optimize operational factors** to achieve the treatment objectives. For treatment systems which rely on **naturally occurring processes**, such as the ponding systems, by en large, the IETS operator/supervisor is **not in control** of the processes, hence is not able to optimize process conditions to ensure discharge compliance.

Biological treatment processes (BPs) have well defined **performance monitoring parameters** to indicate how the processes are occurring in the bioreactors. This module will equip the participants with the required **general working concepts** of performance monitoring of BPs before going into the discussion on how to control the following BPs:

Suspended growth systems

- Activated sludge process and its variants
- Conventional activated sludge (CAS)
- Extended aeration activated sludge (EAAS)
- Sequencing batch reactors (SBR)
- Oxidation ditch (OD)

Anaerobic systems

- Upflow anaerobic sludge blanket (UASB)

Attached growth systems

- Trickling filter (TF)
- Rotating biological contactor (RBC)

Ponding systems (Stabilization ponds)

- Aeration ponds
- Maturation ponds
- Facultative ponds
- Aerated lagoons

6.1.2 General working concepts in biological treatment of industrial effluents

In any biological treatment process, and especially for an activated sludge process, the two most important concepts to grasp are:

- **Oxygen demand**
- **Solids inventory**

Other additional concepts which are also important in IETS (BP) performance monitoring discussed in this module include:

- **pH**
- **Dissolved oxygen**
- **OUR and SOUR**
- **SVI**
- **F/M ratio**
- **Sludge age**
- **Nutrients**
- **Respirometry**
- **ORP**
- **Microbiological examination**

The participants will experience **hands on session/practical demonstrations** of the concepts discussed in this module in the **laboratory session**.

6.2 Measuring oxygen demand

There are primarily **two methods** of determining the oxygen demand of an industrial effluent, namely the **biochemical oxygen demand** (BOD) and the **chemical oxygen demand** (COD).

6.2.1 Biochemical oxygen demand (BOD)

BOD can be understood to be the **amount of oxygen** used by the microorganisms to **biochemically biodegrade** the organic matter in the effluent. The more the amount of organic matter in the effluent, the bigger the amount of oxygen required by the microorganisms to biodegrade the organic matter, hence the more BOD the effluent has. The **organic strength**

of an effluent is measured in terms of its BOD; the stronger the effluent is the bigger is its BOD, hence the bigger is its **pollution potential**.

In the test to measure BOD, microorganisms will decompose the **biologically oxidizable organic matter** in the effluent. BOD_5 test which is commonly used in water pollution field, **takes five days** to complete before the BOD result is available. DO measurements are made at the **beginning** and **end of the five day incubation period**. Because BOD value is related to the organic strength and pollution potential, BOD can be used to measure the **IETS efficiency**. BOD measurements are conducted on a **routine basis** by IETS technicians on samples from various parts of the IETS. The treatment efficiency (i.e. % removal or reduction) can be determined if we have the information on the BOD of the IETS's **influent** and **effluent**.

$\frac{BOD_{influent} - BOD_{effluent}}{BOD_{influent}}$ Treatment efficiency can be computed by using the formula:

$$\text{Treatment efficiency (\%)} = \frac{BOD_{influent} - BOD_{effluent}}{BOD_{influent}} \quad \text{..... (Equation 6.1)}$$

6.2.2 Chemical oxygen demand (COD)

The second commonly used method to measure the oxygen demand of an effluent is the chemical oxygen demand (COD). This test uses a **strong oxidizing agent**, potassium dichromate ($K_2Cr_2O_7$) to oxidize the organic matter contained in the effluent and some inorganic compounds. COD is invariably always **bigger** then BOD because more organic compounds are oxidized in the test. COD test results can be obtained in **3-4 hours** as compared to BOD_5 results in 5 days. But, COD does not only measure the biodegradable organic matter but **all components which can be oxidized** by the oxidizing agent including some inorganic components. Just like BOD, COD measurements are also conducted on a **routine basis** by

IETS technicians on samples from various locations of the IETS. COD is considered to be a **better operational parameter** for monitoring the performance of IETS because the analytical results can be obtained more quickly than BOD.

The treatment efficiency (i.e. % removal or reduction) can also be determined based on COD information of the **influent** and **effluent** by using the formula:

$$\text{Treatment efficiency (\%)} = \frac{COD_{influent} - COD_{effluent}}{COD_{influent}} \quad \text{..... (Equation 6.2)}$$

6.2.3 Comparison between BOD and COD

The advantages and disadvantages of BOD and COD tests to measure the oxygen demand of an effluent as well as an IETS operational parameter are summarized in Table 6.1.

Table 6.1: Advantages and disadvantages of BOD and COD test

Test	Advantages	Disadvantages
BOD	Measures the **biodegradable portion** of the organic matter in the effluent, hence indicates actual impact of effluent discharge to receiving water.	Takes **five days** to obtain test results, hence not useful as an IETS operational tool.
COD	Measures the **total organic matter**, but does not distinguish the portion which is biodegradable, hence does not reflect actual impact to receiving water	Takes **three to four hours** to obtain test results, hence adjustment to IETS operational parameters can be made promptly.

For a specific effluent which does not exhibit a high variability in effluent characteristics, a correlation between BOD and COD can be established.

Once the correlation has been established, the corresponding BOD values can be computed after the COD measurements have been made. Compliance with the regulated discharge standards for both parameters can then be ascertained. If necessary, prompt corrective actions can be made to IETS operational parameters to maintain regulatory compliance.

6.2.4 From the perspective of DOE officer/inspector

As a DOE officer/inspector, you understand that BOD and COD measurements are an integral part of the operation of an IETS-BP. From the operational standpoint, COD monitoring is typically used as a process control parameter while BOD is measured to assess compliance with the regulatory discharge standard.

6.3 Solids inventory

Suspended solids in any biological reactor, such as the aeration tank of an activated sludge system (**mixed liquor suspended solids-MLSS**) are made up of **organic** and **inorganic solids**. The organic solids are also known as **volatile solids matter** (**mixed liquor volatile suspended solids-MLVSS**), which consist of **living** and **nonliving organic.** The different components of solids are shown in the Figure 6.1.

In practice it is difficult to measure living organic matter. Instead, **mixed liquor volatile suspended solids (MLVSS)** is measured as an **estimate** for living organic matter. It is important to realize that a portion of MLVSS is made up of the nonliving matter.

MLSS is typically measured using the **standard test** for determining SS of a water sample whereby in this case, for an AS system, the sample is the mixed liquor sample from the aeration tank. Alternatively, a MLSS meter which gives a digital read out can also be used. MLVSS requires further test to be conducted which needs a muffle furnace to burn off the organics. In an IETS, if the equipment to measure MLVSS is not available, the

mixed liquor suspended solids (MLSS) can still be used as an alternative for computing the solids inventory. MLSS is even a cruder estimation than MLVSS for the living matter. IETS technicians conduct MLSS and MLVSS analysis routinely as part of standard procedure to monitor and control biological treatment processes.

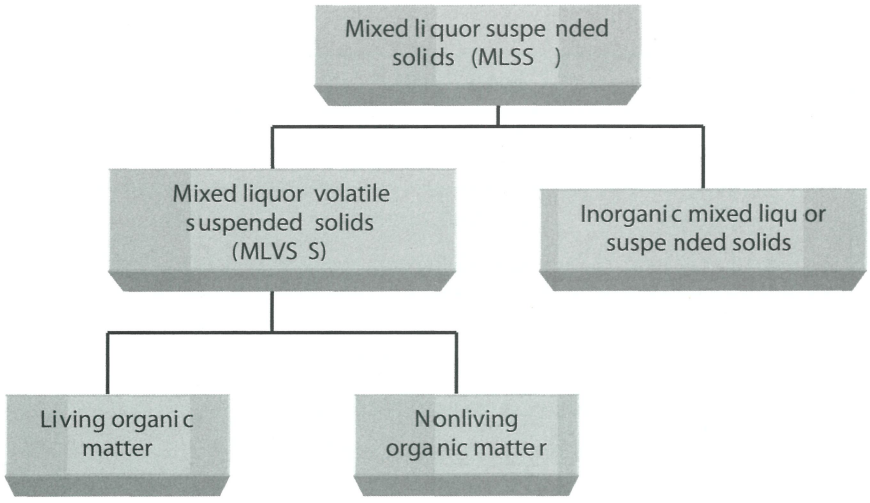


Fig 6.1: Different components of suspended solids in a biological treatment process (Source: WEF, 2006)

Solids Inventory (SI) in an activated sludge (AS) system refers to the **number of microorganisms** in the aeration tank. Because it is difficult to measure the actual number of microorganisms we **estimate** it by using MLVSS. SI is extremely important in the operation of an activated sludge process because the process is controlled essentially by **managing the number of microorganisms** in the process in relation to the food available to them.

The formula for (SI) in an AS system is:

$$\text{SI, kg} = \frac{\text{aeration tank volume, m}^3 \times \text{MLVSS, mg/L}}{1{,}000} \quad \text{.... (Equation 6.3)}$$

The above formula does not take into account the solids in the clarifier.

If MLSS is used instead of MLVSS, a higher SI is obtained. MLVSS is typically about **70% to 80%** of MLSS.

Typical MLSS concentration for different AS variants is given in Table 6.2.

Table 6.2: Typical MLSS concentration for different types of AS system

BP type	MLSS, mg/L
CAS	2000-3500
EAAS	3000-5000
CSAS	contact chamber: 1200-2000 stabilization chamber: 4,000-6,000

Note: CAS: Conventional activated sludge;
EAAS: Extended aeration activated sludge;
CSAS: Contact stabilization activated sludge

6.3.1 From the perspective of DOE officer/ inspector

As a DOE officer/inspector, you understand that MLSS and MLVSS monitoring is part and parcel of the operation of an IETS-BP. MLSS and MLVSS measurements are made on a routine basis to ensure **sufficient microorganisms** are maintained in a biological reactor. Additionally, with other parameters, MLSS and MLVSS data provide essential information that can be used to **control** a biological treatment process (BP), especially, an activated sludge (AS) process.

6.4 pH

A functional definition of pH is the measurement of the **acidity** or **alkalinity** of a solution. pH is a direct measure of acid content [H+] and is commonly indicated on a scale of 0 to 14, where pH 7 is considered neutral, with lower pH values being

acidic and higher values being **alkaline**. Among the reasons for measuring pH in the treatment of industrial effluent containing organic contaminants include:

(i) **Microorganisms** work best within certain pH range (**optimal range**: 6.5-8.5); hence this pH range needs to be monitored and maintained.
(ii) Most IETS will have concrete structures which are susceptible to **corrosion** if exposed to extreme pHs.
(iii) Certain chemical aids such as polyelectrolytes have **optimal pH range** for best application.

In an IETS, pH is closely monitored especially if the effluent exhibits a **wide fluctuation** in pH. Nowadays, pH monitoring is typically accomplished by using automatic pH measurement systems. pH monitoring is important in any biological treatment process, irrespective of the type of process, whether it is a suspended growth or an attached growth system or a batch or a continuous process.

6.4.1 From the perspective of DOE officer/ inspector

As a DOE officer/inspector, you understand that pH monitoring is essential to ensure **optimum pH range** is maintained in the aeration tank for optimal biological treatment process to occur, hence quality effluent is assured on a continuous basis.

6.5 Dissolved oxygen (DO)

Dissolved Oxygen (DO) is one of the most critical measurements in an aerobic biological treatment system (BP). **Aerobic bacteria** require dissolved oxygen to live and carry out the microbiological activities. The DO level required to be maintained in the aeration tank depends on the design and mode of operation of the BP. For example, an activated sludge process which is operated as a **conventional process (CAS)** needs a DO in the range of 2 to 4 mg/L while an **extended aeration process (EAAS)** requires a DO in the range of 4 to 6 mg/L.

DO in aeration tank can be measured using **hand-held DO meters** or **on-line DO analyzers**. However, hand-held DO instruments will only provide a **snapshot** information of the DO in an aeration tank. The disadvantages of using hand-held DO meters include the following:

(i) Hand held DO meters **cannot detect** when more air is required to handle a higher organic load (for example during peak hours of intense manufacturing activities) or when air requirement is lower due to low organic loading (typically during night time hours, when factory manufacturing activities are reduced).

(ii) If a hand-held DO meter is used for controlling air supply, the reduction or increase of air supply must be manually initiated by an **operator** on site if power savings are to be attained.

(iii) If during reduced organic loads (hence low air requirements) air supply is not reduced, valuable energy (hence cost) will be wasted and this may also lead to **sludge bulking** problems.

With the advancement in DO measurement technology and advent of **portable DO meters** the monitoring of the DO in aeration tanks can now be accomplished in a much simpler and faster fashion. However, controlling the biological process in an aeration tank based on manual DO monitoring using simple to use portable DO meters still suffers from the limitation of how many times the measurement is taken. If **process conditions** change between measurement periods the IETS operator is unable to optimize the oxygen supply with the demand by manual adjustment of the blowers. This shortcoming of manual DO measurement has been overcome with **continuous DO measurement** using on line DO meters which is integrated with **blower energy efficiency control strategies** which depend on oxygen delivery systems. For example, control for mechanical aerators and blowers typically involves the use of variable frequency drives (VFDs). For diffused aeration systems using constant speed centrifugal blowers the control strategy is to modulate the air inlet valves or inlet guide vanes while positive displacement blowers are controlled using a VFD to modulate the output. VFD adjusts the speed of electric motors by modulating the power being delivered. Table 6.3 summarizes the disadvantages of high and low D.O. level to a biological treatment system.

Table 6.3: Summary of the disadvantages of high and low D.O. level

Disadvantages of high DO level	Disadvantages of low DO level
(i) Waste of energy hence cost (ii) Promotion of filamentous organisms (iii) Promotion of pin floc organisms in final clarifiers.	(i) Insufficient biological activity, worst case is destruction of bio mass. (ii) Uncontrolled stressing of bugs, anaerobic zone instead of aerobic zone.

6.5.1 From the perspective of DOE officer/ inspector

As a DOE officer/inspector, you understand that an IETS-BP cannot be operated and controlled without DO monitoring. **Extreme levels of DO**, whether on the high or the low side will bring negative impact on the performance of the IETS, hence its discharge quality. Various methods have been developed to **optimize DO requirements** in an IETS-BP.

6.6 Oxygen uptake rate (OUR) and specific oxygen uptake rate (SOUR)

Oxygen uptake rate (OUR) is one of the most valuable performance monitoring parameters available to operators of activated sludge processes. The OUR test will tell us how fast the microorganisms are **metabolizing** the available organic matter (termed as substrate), represented as BOD or COD. OUR and SOUR show the **rate at which oxygen is used by the microorganisms.** The OUR and SOUR data can then be compared with the **typical ranges** commonly found in practice to see if the rate of food biodegradation is occurring at a normal rate or a faster or slower rate than normal or not at all. From this information some conclusions can be derived and relevant changes can then be made to the **operational parameters** of the activated sludge system in order to ensure optimal efficiency.

OUR test is a simple procedure which utilizes a dissolved oxygen (DO) meter with probe adapted to BOD bottle. The OUR is determined by measuring the amount of DO that is depleted from a sample of mixed liquor in 15 minutes. The OUR is expressed as milligrams of oxygen used per liter of mixed liquor per hour (mg O_2/L.h). The SOUR test gives results in milligrams of oxygen used per hour per gram of mixed liquor volatile suspended solids (mg O_2/h per g MLVSS).

SOUR = OUR/MLVSS.....(Equation 6.4)

A sudden decrease in SOUR may indicate **toxicity** to the microorganisms resulting in reduced microbiological activity. Table 6.4 shows typical range of OUR values for different situations.

Table 6.4: Typical range of SOUR values for different situations of microbial growth

SOUR, $\frac{mgO_2/hr}{g. MLVSS}$	Nature of microbial growth/ microorganism involved	Floc description, settling characteristic
> 20	Logarithmic growth/ Flagellates	Dispersed floc, Settling Slow
12-20	Declining growth/ Ciliates	Flocs forming, Settling normal
< 12	Endogenous respiration/ Rotifers and higher life	Pin floc, Settling fast

6.6.1 From the perspective of DOE officer/ inspector

As a DOE officer/inspector, you understand that OUR and SOUR are useful operational parameters to ensure microorganisms in your biological system are **actively biodegrading** the organic matter. An IETS-BP which is performing in an optimal fashion will exhibit a SOUR in **normal range**. Should SOUR go out of the acceptable range, you would know that IETS is experiencing some form

of **toxicity** which will be reflected in the deterioration of the **effluent quality**. Investigation must be made promptly to identify the cause and **corrective actions** taken immediately.

6.7 Sludge volume index

In the biological reactor such as the aeration tank, the microorganisms convert the organic matter to carbon dioxide, water, energy and biomass. The next important step is to separate the biomass from the mixed liquor. This **separation process** takes place in the clarifier. The biomass (sludge) must have **good settling properties** in order solid separation to take place efficiently thus resulting in a **clarified final effluent.**

The sludge volume index (SVI) is a measure of the **settleability characteristics** of the biomass, and it expresses this as the volume occupied per unit of biomass. It is generally expressed in mL/g after 30 minutes settling, or the SVI_{30} value. The smaller the SVI value is the better the settling property of the sludge is. A mixed liquor with a low SVI will **settle well** and will produce a more **compact sludge**.

SVI can be calculated using the formula:

$$SVI = \frac{SSV_{30}}{MLSS} \times 1000 \quad \text{.....(Equation 6.5)}$$

Where:

SVI = Sludge volume index, mL/g
SSV_{30} = Volume of settled solids in one-liter graduated measuring cylinder after 30 minutes settling period, mL/L
MLSS = Mixed liquor suspended solids, mg/L

SVI test follows a simple procedure which uses a graduated 1000 mL measuring cylinder filled with a sample of mixed liquor. The data on settled sludge volume after 30 minutes and MLSS is used to compute the SVI.

Table 6.5 gives a guide on SVI and settling property of the sludge.

Table 6.5: Guide on sludge volume index and sludge settling property

SVI, mL/g	Interpretation	Result and implication
<50	Sludge settles exceptionally well	Clarified final effluent
50-100	Good sludge settling property	Good quality effluent
100-150	Acceptable settling property	Acceptable effluent quality
>150	Bulking sludge-sludge high in filamentous growths	Operational problems in secondary clarifier; solids carry over in final effluent resulting in SS noncompliance and reduction of sludge concentration in aeration tank

6.7.1 From the perspective of DOE officer/inspector

As a DOE officer/inspector, you understand that SVI is an indicator of the **sludge settelability characteristics** that will determine how well SS separation will take place in the secondary clarifier. You would need to inspect factory records to ensure the IETS operators monitor SVI routinely and maintain it within the acceptable range.

6.8 Food to Microorganism (F/M) ratio

The F/M ratio is a performance monitoring parameter that is used you determine the proper number of **microorganisms** for a biological treatment system relative to the **food** available. The "food" in the ratio is the carbonaceous biochemical oxygen demand (CBOD) entering the biological process. The "microorganisms" are the activated sludge solids in the aeration tanks, which are measured as mg/L of mixed liquor volatile suspended solids (MLVSS). To maintain a desired CBOD and SS removal efficiency on a consistent basis, the F/M ratio must be maintained within the **acceptable range** for the type of biological treatment process (BP) being employed at the IETS premise. Table 6.6 summarizes typical F/M ratios for different types of AS system.

Table 6.6: Typical F/M ratios for different types of AS system

AS type	F/M, kg BOD/kg MLVSS.d
CAS	0.2-0.5
EAAS including OD	0.05-0.15
CSAS	0.2-0.6

Note: CAS: Conventional activated sludge; OD: Oxidation ditch,
EAAS: Extended aeration activated sludge;
CSAS: Contact stabilization activated sludge

To determine F/M ratio, the following information is required:

(i) Influent flow into the biological reactor, such as the aeration tank of an AS system
(ii) Influent CBOD concentration into the aeration tank.
(iii) MLVSS concentration in the tank
(iv) Volume of aeration tank

The formula to calculate F/M ratio is:

$$F/M, d^{-1} = \frac{\text{Influent flow , } m^3/d \times \text{BOD, mg/L}}{\text{Aeration tank volume, } m^3 \times \text{MLVSS, mg/L}} \quad \text{.....(Equation 6.6)}$$

The correct BOD to be used is the influent **carbonaceous BOD** (CBOD) concentration.

6.8.1 From the perspective of DOE officer/inspector

As a DOE officer/inspector, you understand that F/M ratio is an important parameter that needs to be monitored **regularly** to ensure **optimum** food available (represented by BOD or COD) compared to the microorganisms (represented by MLVSS) is maintained. The optimum

F/M value is dependent on the type of biological treatment process (BP). The performance of BPs which are operated with F/M values outside the acceptable range will be seriously affected, hence produce unsatisfactory effluent quality.

6.9 Sludge age

Sludge age is the average time **microorganisms** remain in the biological treatment system before they exit the system. Sludge age is considered to be the **key activated sludge operating parameter**. Similar concepts which were used in the past include mean cells residence time (MCRT) and solids retention time (SRT) which may use slightly different formulae. Sludge age (θ_c) can be considered to be the reciprocal of F/M ratio. θ_c is calculated by using the following formula:

$$\text{Sludge age } (\theta_c) = \frac{\text{MLSS} \times V_R}{\text{WAS} \times Q_{WAS}} \quad \text{.....(Equation 6.7)}$$

Where,

(θ_c) = sludge age, days
V = aeration tank volume, m^3
MLSS = mixed liquor suspended solids concentration, mg/L
Q_{was} = sludge wasting rate, m^3 per day
WAS = SS concentration of the waste sludge, mg/L

Table 6.7 summarizes typical sludge (θ_c) for different types of AS system.

Table 6.7: Typical sludge (θ_c) for different types of AS system

AS type	θ_c, d
CAS	5-15
EAAS including OD	15-30

Note: CAS: Conventional activated sludge; OD: Oxidation ditch, EAAS: Extended aeration activated sludge.

6.9.1 From the perspective of DOE officer/ inspector

As a DOE officer/inspector, you understand that sludge age (θ_c) is a practical **operational parameter** that needs to be computed **on a regular basis** to ensure the age of the microorganisms that has been designed for the IETS is maintained. The optimum θ_c is dependent on the type of biological treatment process (BP). To ensure the desired effluent quality is achieved on a sustained basis, the BPs must be operated with θ_c values within the acceptable range. For some BPs, such as the ponding systems, the concept of θ_c is not applicable.

6.10 Nutrients

Cells are composed of approximately 2.5% phosphorus and 12.4% nitrogen. Hence, microorganisms need **sufficient nutrients** for growth and to enable them to break down the organic matter in the effluent. The two key nutrients are **nitrogen** and **phosphorus**. In an IETS they are monitored on a regular basis to ensure that the **ratio of the organic matter and the nutrients** is maintained in a certain proportion. The guideline typically used is to ensure a ratio of BOD:N:P of 100:5:1 is maintained in the incoming effluent to the aeration tank for aerobic treatment and 250:5:1 for anaerobic treatment. Within industrial effluent treatment systems, nitrogen exists in several forms such as:

(i) Soluble ammonia or commonly known as ammonium (NH_3 as a gas or NH_4^+ ions)
(ii) Organic nitrogen (urea, fecal material)
(iii) Nitrate (NO_3^-) and nitrite (NO_2^-)
(iv) Total Kjeldahl Nitrogen (TKN) is the combination of ammonia and organic nitrogen.

Phosphorus is typically found as **orthophosphate**, **polyphosphate,** and **organic phosphate**. Orthophosphates (H_3PO_4) are readily available as nutrients. Polyphosphates, which are chains of phosphorus-based molecules, must be converted to orthophosphates via hydrolysis prior to utilization as a nutrient.

Organic phosphates also must be converted to orthophosphate to be available as a nutrient.

Industrial effluents from many industries **do not** contain sufficient Nitrogen and Phosphorus, hence **nutrient addition** is necessary. Common chemical compounds used for supplying N and P to the IETS are:

(i) Ammonium carbonate; ammonium chloride; ammonium phosphate; ammonium sulfate
(ii) Phosphoric acid; monosodium phosphate; disodium phosphate; ammonium phosphate.

Nutrient addition can be made directly to the **aeration tank** or dosed into the **influent line** before the influent enters the aeration tank.

6.10.1 From the perspective of DOE officer/ inspector

As a DOE officer/inspector, you understand that there is a need to ensure that the nutrient must be made available to the biological treatment process (BP) and maintained within the **correct ratio**. You should enquire about the nutrient levels and the ratio should be computed on a scheduled basis. Insufficiency in nutrients will adversely affect the performance of the IETS.

6.11 Oxidation reduction potential (ORP)

Oxidation reduction potential (ORP) theory is best described as an indication of the ability of a solution to **oxidize** or **reduce** another solution. The ORP of an effluent is the sum total of the potentials of all constituents present in it. The ORP value of the effluent may change upon introduction of a new constituent or when the concentration of a constituent changes. Typically, ORP scale varies from -2000 mV to +2000 mV, where a positive ORP reading indicates that the effluent possesses an **oxidizing property** while a negative reading indicates that the effluent

has a **reducing property**. In effluent treatment scenarios, typical **reducing agents** include sulfur dioxide, sodium metabisulfite, and organic matter while common **oxidizing agents** are chlorine, hydrogen peroxide and oxygen. From the ORP value of the effluent the IETS supervisor/operator knows if the effluent is **oxidizing** (positively charged, i.e. positive mV values) or **reducing** in character (negatively charged, i.e. negative mV values), what **biochemical reaction** is occurring and whether **operational conditions** of the IETS should be changed to promote or prevent specific reactions.

The application of redox reactions and hence the use of ORP in **physical chemical treatment processes** (PC) of industrial effluents is widely known. Examples of such application are the reduction of chromium IV to chromium III in hydroxide precipitation process and removal of cyanide via alkaline chlorination method. However, the application of ORP in the monitoring of biological treatment processes (BPs) has only recently become prominent, probably due to lack of understanding of its applicability to BPs. When employed in an IETS, ORP will dictate whether a specific **biological reaction** (redox reaction) will occur.

Important **redox reactions** in IETS and sewage treatment system (STS) include nitrification, denitrification, biological phosphorus removal, biological production of foul-smelling gases, and the biodegradation of organic matter (removal of carbonaceous biochemical oxygen demand - cBOD). Table 6.8 shows details of type redox reactions generally encountered in an IETS-BP and the chemical species/compounds involved.

Table 6.8: Type of redox reactions generally occurring in an IETS-BP and the chemical species/compounds involved.

Redox reaction	Species involved	Oxidized state (containing oxygen)	Reduced state (containing hydrogen)
cBOD biodegradation	C	CO_2	-
*Nitrification	N	NO_3^-	NH_3
*Denitrification	N	NO_3^-	NH_3
*Biological phosphorus removal	P	PO_4^{2-}	-
*Biological malodorous gases production	S	$SO4^{2-}$	H_2S

Note: cBOD: carbonaceous BOD; * typically more relevant to sewage treatment

ORP can be measured with the use of an ORP meter by inserting the ORP probe directly into the **aeration tank**, typically about 0.6 m below the mixed liquor surface. Instantaneous ORP readings give useful snapshot information that can be used by IETS supervisors/operators:

(i) as IETS treatment **efficiency indicator**
(ii) to identify **treatment problems** before they affect effluent quality.

Table 6.8 summarizes typical biochemical processes, reactions in an IETS and their corresponding ORP values.

Table 6.9: Typical biochemical processes, reactions in an IETS and corresponding ORP (Adapted from YSI Environmental)

Biochemical Process	Biochemical Reaction/process	ORP, mV
*Nitrification	NH_3 is converted to NO_3^- by nitrifying bacteria	+100 to +350
cBOD degradation with free molecular oxygen	Bacteria + Organic matter + oxygen→ Cells + CO_2 + H_2O	+50 to +250
*Soluble phosphorus conversion to solid in aerobic environment	-	+25 to +250
*Denitrification (anoxic condition)	NO_3^- is converted to N_2 by denitrifying bacteria	+50 to -50
Sulfide formation	SO_4^{2-} to H_2S	-50 to -250
*Biological phosphorus release into solution in an anaerobic tank	Volatile fatty acids are produced by fermentative bacteria	-100 to -250
Hydrolysis and acidogenesis (acid formation)	Sugars, ammo acids, fatty acids are fermented to acetate, propionate, butyrate, lactate, ethanol, carbon dioxide, and hydrogen	-100 to -225
Methanogenesis (methane production)	Acetate , H_2/CO_2, formate, methanol, methylamines, and CO are converted to CH_4	-175 to -400

Note: * Typically more relevant to sewage treatment

6.11.1 From the perspective of DOE officer/ inspector

From the ORP values as summarized in Table 6.7 the DOE officer/ inspector knows if the **reactions** that need to be maintained in the IETS are occurring or the reactions that he wants to prevent are being supressed. Appropriate corrective actions can be taken accordingly by the IETS operator to address any unsatisfactory conditions in the IETS.

6.12 Respirometry

Respirometry is a technique used in the field of sewage and industrial effluent treatment for obtaining estimates of the **rates of metabolism** of microorganisms. The OUR and SOUR measurements discussed in section 6.6 are **manual versions** of respirometric technique to measure the respiration rate of microorganisms while they are **biodegrading** the organic matter. Nowadays the respiration rate can be measured with a respirometer which is equipped with **computer controlled systems** to run on an automatic mode and has the capability to perform **statistical analysis** and generate respirographs. **Respirograph** are graphical plots that show the way in which the respiration rate of a biomass changes as the biodegradable organic matter present is used up. In some cases the **aeration tank** of the IETS itself can be adapted to serve as a respirometer to measure the respiration rate of microorganisms in the IETS under the prevailing load and environmental conditions. Respirometers work on the basis of the principle that the metabolic rate of the micororganisms is reflected by the rate of **dissolved oxygen consumption**. This rate can be measured by several means: either directly, by measuring the dissolved oxygen concentration in the liquid phase, or by measuring the gaseous oxygen concentration, or by measuring the changes in gaseous oxygen concentration.

In effluent treatment field, over the last few years, there has been a growing interest in the use of respirometers for IETS operation and control. In particular, respirometers have found application in the following areas; they can be used to:

(i) measure **oxygen utilization** rates
(ii) measure the impact of **toxic shock** events
(iii) measure the impact of changes to **operational parameters**
(iv) provide **early warning** on process upsets hence activate alarms
(v) provide a measure of the **health** of the biomass
(vi) measure **short-term BOD**

6.12.1 From the perspective of the DOE officer/ inspector

As a DOE officer/inspector, you understand that a respirometry is a very powerful technique that gives a complete picture of how the IETS (BP) is operating. Nowadays a respirometer is available that can be used as an **effective tool** to assist the IETS operators in the operation and control of the IETS. If used in in-line mode, the instrument provides **real time** crucial information on the **health status** of the biomass in the IETS hence assists the IETS supervisor/operator in making **informed decision** to make changes to IETS operational parameters, if necessary.

The respirometer can be utilized for a variety of purposes including feeding and aeration **optimization** measures.

6.9 Microscopic examination of microorganisms

The **workhorses** responsible for primary removal of **organic matter** within an IETS-BP are a number of different types of **microorganisms**. These microorganisms can be classified as either **bacteria**, **protozoans** or **metazoans**. The IETS supervisors/ operators need to have a working knowledge of the various types of organisms, their functions and properties in order to understand the fundamental principles involved in biological treatment processes (BPs) and consequently be able to control the BPs.

The majority of the microorganisms responsible for biodegradation of organic matter are the bacteria. Bacteria are the lowest life form which are single-celled

organism. The absence or presence of free oxygen will determine if the sludge is anaerobic or aerobic.

The lowest life form identified within treatment plant sludge is bacteria. One of the properties of bacteria is that they usually live in a colonial structure called floc. The structural nature and characteristics of a significant portion of the floc particles directly affect **physical properties** that contribute to treatment plant efficiency. The floc particles may be identified for shape, size, strength, surface area, density and the presence of higher life forms

Fig. 6.2 and 6.3 show typical microorganisms found in biological treatment processes.

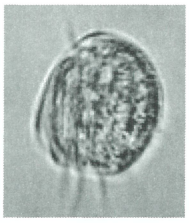
The roles played by different types of microorganisms are summarized in Table 6.10.

Table 6.10: The roles played by different types of microorganisms

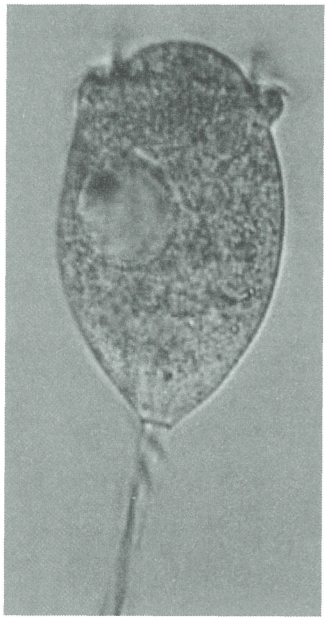
Microorganisms	Function
Protozoa 1.Crawling ciliates	"Crop" bacteria from floc surface and improve sludge settelability
2.Stalked ciliates	Attached to flocs with stalks, feed on small particles using their cilia to clarify effluents
3.Free-sweemming ciliates	Feed on bacterial cells, reducing number of free cells in liquid phase
Multicellular animals (Metazoa) 1.Rotifers	Contribute to floc stabilization
Filamentous organisms	Sludge bulking



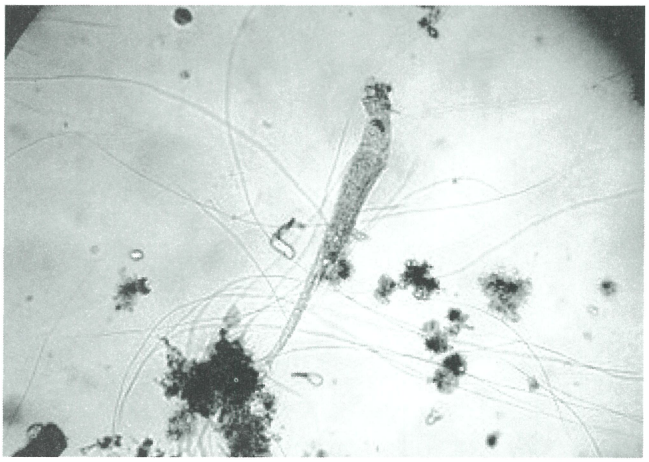
6a: Free swimming cialiates



6b: Crawling ciliates



6 c: Stalked ciliates



7 6: Rotifers

Fig 6.2: Typical microorganisms found in BP (Protozoa: 6a, 6b, 6c; Metazoa: 6d) (Source: Žika Rech, 2008).

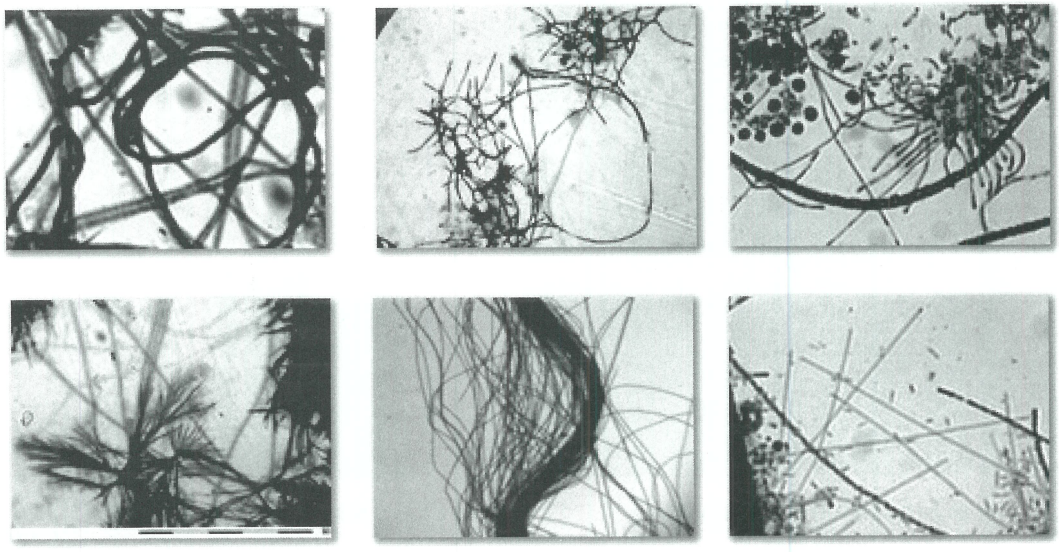
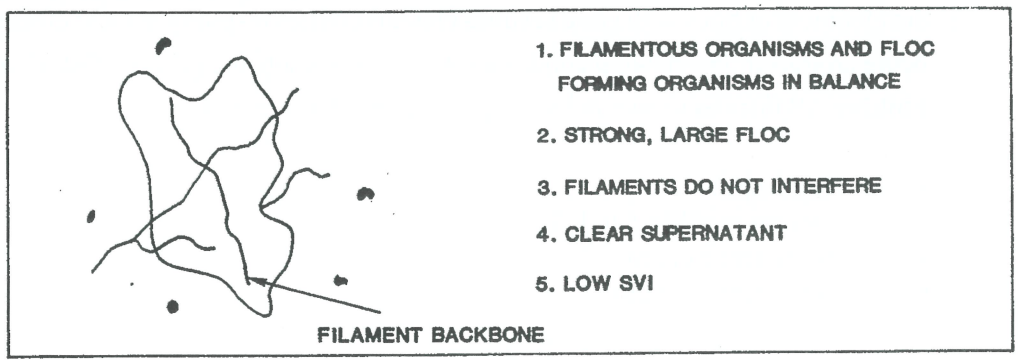
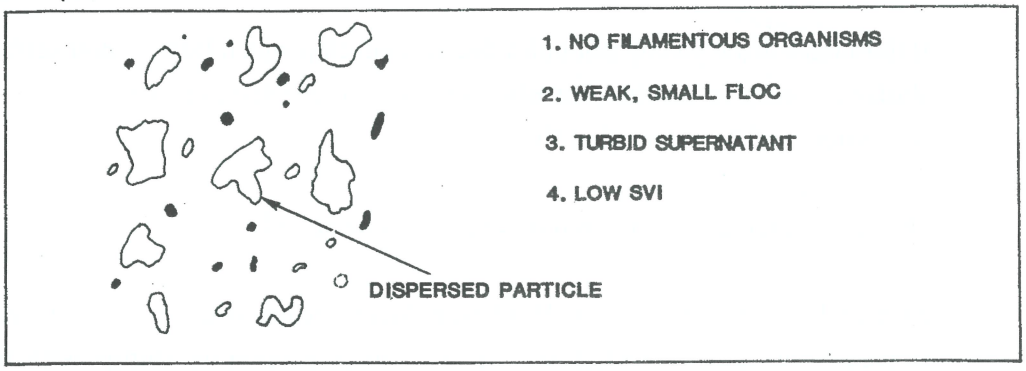


Fig 6.3: Typical microorganisms found in BP: Filamentous organisms (Source: Žika Rech, 2008)

A. Ideal, Non-bulking Activated Sludge Floc.



B. Pin-point Floc.



C. Filamentous Bulking Activated Sludge.

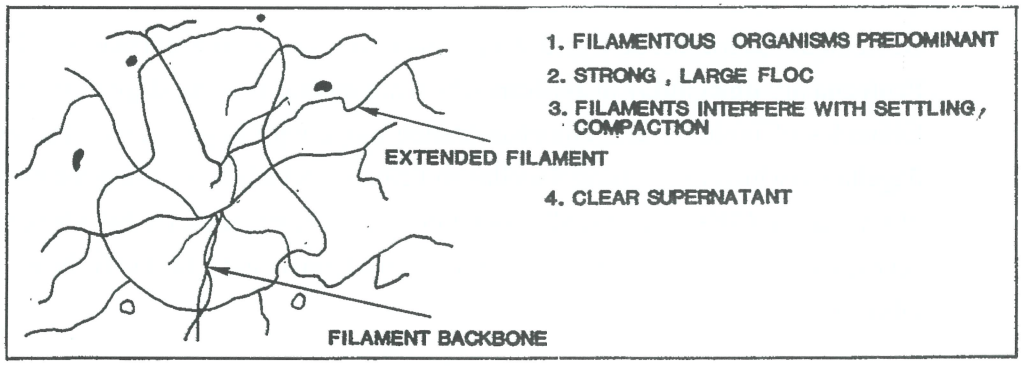


Fig.6.4: Different characteristics of activated sludge flocs (Source: USEPA, 1987)

We need to provide the right conditions in the aerobic process that encourage the development of flocs with **good settling characteristics** resulting in clear effluents being produced. The flowing conditions will help promote the growth of ideal, **non bulking** AS flocs as shown in top diagram (part A) of Fig. 6.4.

- Right age
- Optimum pH (6.5 to 8.5)
- Sufficient oxygen
- Sufficient nutrients

You will not observe many rotifers in this floc.

If the sludge is too young, **pin point floc** will develop which leads to **non settling sludge** resulting in **turbid effluents** being discharged (floc in part B of Fig. 6.4). No rotifers will be observed at all.

On the other hand, if sludge is old, rotifers will be abundant.

Even at the right sludge age, if pH is low, nutrients are inadequate or oil and grease is present in high concentration, you may observe **foaming sludge with few rotifers** (part C of Fig. 6.3).

Other inhabitants of the activated sludge process are protozoa, metazoan and fungi. **Protozoa** are **unicellular organisms** which are mobile at some stage in their life. Examples of protozoa are: amoebae (which move with finger-like protrusions), flagellates (which move using flagella) and ciliates (which move using the motion of tiny hairs). Ciliates are usually found in large numbers in IETS-BP where they act as predators and scavengers, ingesting the bacteria, helping to clarify the treated effluents.

Apart from unicellular microorganisms, there are multicellular animals which are commonly found in IETS-BPs. These are rotifers and worms. **Rotifers** are extremely simple multicellular animals which would feed on smaller microbes or free-swimming bacteria and organic matter helping to **clarify** the effluents from the activated sludge processes.

The free-living **nematodes** are a type of worms commonly found in trickling filters which graze on bacteria, rotifers, and other worms. They assist in stabilizing sludge as well as controlling the biofilm thickness in the filters.

6.10 Controlling various BPs

The relevant parameters for controlling various BPs are summarized in Table 6.8.

Table 6.11: Relevant PM parameters for different BPs

BP type	Relevant parameters
CAS, EAAS,	pH, ORP, BOD, COD, DO, F/M, OUR, SOUR, sludge age, Nutrients; MLSS, MLVSS, microscopic microorganism examination
SBR	pH, ORP, DO, F/M, OUR, SOUR, sludge age, Nutrients; MLSS, MLVSS, microscopic microorganism examination
UASB	VFA, alkalinity, pH, ORP, BOD, COD, SVI, biogas production
TF	pH, BOD, COD, DO
RBC	pH, BOD, COD, DO
Anaerobic ponding system	VFA, alkalinity, pH, sludge depth
Aerobic ponding system	pH, BOD, COD, DO, sludge depth

6.11 From the perspective of DOE officer/inspector

As a DOE officer/inspector you are able to:

(i) Discuss the importance of the concepts of **oxygen demand** and **solids inventory**

(ii) Explain the disadvantages and disadvantages of using **BOD** and **COD** as **performance monitoring (process control) parameters** to monitor the performance of biological treatment processes (BP)

(iii) Discuss the importance of monitoring the following parameters: pH, dissolved oxygen, food to microorganisms (F/M) ratio, sludge age, oxygen uptake rate (OUR), specific oxygen uptake rate (SOUR), sludge volume index (SVI), nutrients, ORP, respirometry and microscopic examination of microorganisms for **optimal operation** of biological treatment processes (BPs) and for process/performance monitoring

(iv) State typical **acceptable range** of values for each of the above parameters

CHAPTER 7:

MAINTENANCE OF IETS-BP COMPONENTS AND PERFORMANCE MONITORING INSTRUMENTS





CHAPTER 7:

MAINTENANCE OF IETS-BP COMPONENTS AND PERFORMANCE MONITORING INSTRUMENTS

7.1 Importance of IETS maintenance program

Industries which run their manufacturing operations on a 24 hour basis CANNOT afford to experience upsets in the operation of their IETSs. Malfunctioning or breakdown of the IETS components resulting **in noncompliant effluent discharge** is NOT acceptable. If this happens, the factory manufacturing operation which generates the effluent needs to be **temporarily shut down** unless the IETS design has incorporated large enough storage capacity for **temporary storage** of **"off spec" effluent**. Even if "off spec" effluent storage is available, the capacity may last only for a couple of days operation, at the maximum. Based on the above analysis, the industries cannot afford to experience an IETS upset situation, especially one due to IETS component/equipment breakdown, which can be prevented in the first place through proper planning. The latter normally takes in the form of a well prepared and implemented **preventive and corrective maintenance program**.

Preventive maintenance refers to maintenance carried out to prevent the failure of IETS components or items by providing systematic inspection, detection and maintenance. Preventive maintenance may be carried out on a scheduled basis (**periodic maintenance**) or may depend on analysis of equipment performance trends (**predictive maintenance**).

Corrective maintenance refers to actions made when an IETS component, equipment or failure or breakdown has already occurred, to bring it back to working order.

7.2 IETS hardware components

Uninterrupted and smooth operation of biological treatment processes (BP) depends on the **hardware components** of the BP processes being maintained properly to prevent the occurrence of breakdown and malfunction. The BP hardware can be categorized into two main groups as follows:

(i) Components that form the **building blocks** of the BP such as reaction tanks, mixers, pumps, piping system, compressors, motors, auxiliary tanks, skimmers, and other associated equipment and parts such as chemical dosing systems, ejectors, valves, etc.

(ii) **Performance monitoring equipment and instrumentation** systems such as, pH sensors and meters, DO sensors and meters, redox meters, BOD associated equipment, COD associated equipment, TOC associated equipment, SS meter, sludge judge meter, spectrophotometer, respirometer, analytical balance, and ovens.

To ensure smooth running and operation of both groups of the above hardware, hence the IETS itself, a well prepared and executed **preventive and corrective maintenance program** is required.

The maintenance of the first group of hardware components is usually not under the responsibility of the IETS team. Typically, in an industrial setting, this important function of drawing up and implementing preventive and corrective maintenance program of IETS components and parts is entrusted to the **engineering department**. However, the second group of hardware is rightly put under the care of the **IETS team** which is also responsible for the calibration activities.

7.3 Common performance monitoring instruments used for monitoring biological treatment processes

In the operation of biological treatment processes (BPs) to treat industrial effluents, the following are the most commonly used PM equipment, meters, instruments and probes:

(i) pH probes and meters
(ii) DO probes and meters
(iii) Redox meters,
(iv) BOD associated equipment and on line BOD analyzers
(v) COD associated equipment
(vi) TOC associated equipment
(vii) SS probes and meters
(viii) 'Sludge Judge" or automatic sludge depth meters
(ix) Respirometer
(x) Spectrophotometer
(xi) Analytical balance
(xii) Ovens.

The success of the treatment depends on the proper functioning of these equipment, probes, meters and instruments to measure the performance monitoring and operational parameters accurately. Proper functioning of the equipment, meters, etc. depends on their upkeep and calibration in accordance with the manufacturer's instructions. The importance of instrument maintenance cannot be over emphasized. Some important aspects of the maintenance and calibration of the probes, sensors and meters are outlined below.

7.4 Installation of PM equipment and instruments

All PM instruments such as DO, pH, and/or ORP probes must be located in places that can be reached easily by IETS operators/technicians. These probes often clog or foul and need cleaning and calibration. If they are not easily accessible, proper maintenance, repair or replacement may not occur. Consideration of proper locations to install PM instruments should have been taken at the IETS design stage.

7.5 Maintenance of instruments according to manufacturers' recommendations

The use of all equipment and instruments for the purpose of carrying out performance monitoring activities must adhere strictly to the **operation & maintenance (O&M)** and **calibration procedure** outlined in the manuals produced by the manufacturers. The **maintenance and calibration records** must be maintained properly and kept at hand for DOE's inspection.

7.6 From the perspective of the DOE officer/ inspector

As a DOE officer /inspector you:

(i) Understand that performance of the IETS-BP depends upon **proper functioning** of all components of the IETS including the PM equipment, instruments and sensors, probes,

(ii) Must check the records to ensure that all the staff assigned the task of conducting PM activities are **fully trained** in the use of the PM equipment and instruments etc. including equipment operation and maintenance (O&M) and calibration

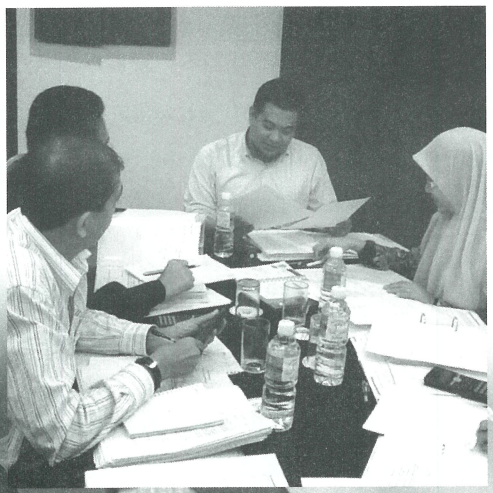
(iii) Must inspect the documentation to ensure that all equipment O&M **manuals and calibration instructions** are properly kept and easily accessible to the IETS technicians/personnel

(iv) Must ensure relevant PM equipment O&M and calibration **checklists/ forms/logs** are developed and properly maintained

(v) Must inspect to ensure all relevant O&M and calibration **records** are maintained.

CHAPTER 8:

BP MATHS





CHAPTER 8:

BP MATHS

8.0 Typical calculations for operation and maintenance of BP

This chapter is dedicated to the **calculations/computations** that are commonly associated with the operation and maintenance of biological treatment processes (BPs). Some of the calculations are follow-up computations based on information obtained from **laboratory experiments** scaled up for practical applications on a real IETS **operational setting**.

The following paragraphs illustrate the computations commonly encountered in the operation of IETS-BP.

8.1 Flowrate

Formula for calculating flowrate is:

$$\text{Average daily flow} = \frac{\text{Totalizer reading}_2 - \text{Totalizer reading}_1}{T_2 - T_1}$$

Where T is time the totalizer reading was taken.

Typical units:

Totalizer reading: m^3; T: h

Example 1:

Calculate the average daily flow in m^3h^{-1} and m^3d^{-1} if the reading on the totalizer on the flow meter at 8.00 am was 15,000 m^3 and at 6.00 pm 20,000 m^3

Answer:

Average daily flow $= \frac{1000\ m^3 - 500\ m^3}{(8\ am - 12\ noon)\ (12\ noon - 6\ pm)\ h}$

$= \frac{500}{10} = 50\ m^3h^{-1}$

$= 50 \times 24\ m^3d^{-1}$

$= 1{,}200\ m^3d^{-1}$

8.2 Detention time

Formula for calculating Detention Time is:

$$DT, d = \frac{V_R, m^3}{Q, m^3d^{-1}}$$

Where,

D.T: Detention time
V_R: Reactor volume
Q: Flow

Example 2:

Calculate the Detention Time in hour for an oxidation pond of 1000 m^3 and influent flow of 100 m^3d^{-1}.

Answer:

$V = 1000\ m^3$

$Q = 100\ m^3d^{-1}$

$$\text{Detention Time} = \frac{1000\ m^3}{100\ m^3d^{-1}}$$

$= 10\ d$

8.3 Solids inventory (SI)

The formula for SI is:

$$\text{SI, kg} = \frac{V_R, \text{m}^3 \times \text{MLVSS, mg/L}}{1{,}000}$$

Where:

V_R: Aeration tank volume

MLVSS: Mixed liquor volatile suspended solids

The above formula does not take into account the solids in the clarifier.

Note that where MLVSS information is not available, MLSS is sometimes used instead of MLVSS. In such a case, a higher SI is obtained. MLVSS is typically about **70% to 80%** of MLSS.

Example 3:

An aeration tank of a conventional activated sludge system has a volume of 200 m^3 and MLVSS concentration of 3500 mg/L. Calculate SI.

Answer:

$$\text{SI, kg} = \frac{200\ \text{m}^3 \times 3500\ \text{mg/L}}{1000}$$

$$= 1750\ \text{kg}$$

8.4 Sludge volume index (SVI)

The formula for calculating SVI is:

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

Where:

SVI: Sludge volume index

SV: Settled sludge volume, mL/L

MLSS: Mixed liquor suspended solids

Example 4:

In a settling test, the following results are obtained:

SV_{30} = 800 mL/L; MLSS = 4000 mg/L

Calculate SVI.

Answer:

Using the above formula:

$$SVI = \frac{SV_{30} \times 1000}{MLSS}$$

$$= \frac{800 \times 1000}{4000}$$

$$= 200 \text{ mL/g}$$

8.5 Food to Microorganism (F/M) ratio

The formula for calculating (F/M) is:

$$F/M, d^{-1} = \frac{Q, m^3/d \times BOD, mg/L}{V_R, m^3 \times MLVSS, mg/L}$$

Where:

Q: Influent flow

$V_{R:}$ Aeration tank volume

MLVSS: Mixed liquor volatile suspended solids

Note that M is also equal to SI.

Example 5:

Determine F/M if the influent flow is 100 m^3/ d and has a BOD concentration of 250 mg/L while the aeration tank volume is 200 m^3 and has a concentration of MLVSS of 3000 mg/L.

Answer:

Using the formula above:

$$F/M = \frac{100 \times 250 \text{ kg/d}}{200 \times 3000 \text{ kg}}$$

$$= 0.04 \text{ d}^{-1}$$

8.6 Sludge age (θ_c)

The formula for calculating sludge age is:

$$\theta_c, \text{d} = \frac{\text{kg MLVSS}_{\text{in the aeration tank}}}{[\text{kg VSS}_{\text{in waste sludge}}/\text{d}] + [\text{kg VSS}_{\text{in effluent}}/\text{d}]}$$

Where:

MLVSS: Mixed volatile liquor suspended solids
VSS: Volatile suspended solids concentration

Note: VSS should be used in the computation. If VSS information is not available it can be substituted with SS but the two should not be mixed. A more precise calculation would include solids in the clarifier.

Neglecting the SS in the effluent, and using MLSS instead of MLVSS, the formula for calculating sludge age (θ_c) is:

$$\theta_c = \frac{\text{MLSS, mg/L} \times V_R, \text{ m}^3}{\text{WAS, mg/L} \times Q_{WAS}, \text{ m}^3/\text{d}}$$

Where:

MLSS: Mixed liquor suspended solids
V_R: Aeration tank volume
WAS: Waste activate sludge suspended solids concentration
Q_{WAS} : Flow rate of waste activate sludge

Example 6:

An extended aeration activated sludge system was operated with the following conditions: Mixed liquor suspended solids = 5400 mg/L; volume of aeration tank = 2000 m^3; wasted sludge suspended solids concentration = 4000 mg/L; wasted sludge flow rate = 100 m^3/ d.

Calculate the sludge age in days.

Answer:

MLSS = 5400 mg/L

V_R = 2000 m^3

WAS = 4000 mg/L

Q_{WAS} = 100 m^3/ d

Using the above formula:

$$\text{Sludge age } (\theta_c) = \frac{\text{MLSS} \times V_R}{\text{WAS} \times Q_{WAS}}$$

$$= \frac{5400 \text{ mg/L} \times 2000 \text{ m}^3}{4000 \text{ mg/L} \times 100 \text{ m}^3/\text{d}}$$

$$= 27 \text{ d}$$

Example 7:

If the operator of an AS system wastes 5% of the sludge from the system daily, what would be the average length of time the sludge remains in the system?

Answer:

Assuming the solids (i.e. microorganisms) in the effluent can be ignored, the length of time the microorganisms remain in the system (i.e. the sludge age, θ_c) is:

$$\theta_c = \frac{100\%}{5\% \text{ per d}}$$

$$= 20 \text{ d}$$

Therefore, θ_c = 20 d

8.7 Oxygen uptake rate (OUR)

To compute OUR, you should plot a graph of O_2, mg/L versus Time, min. The gradient of the graph gives you the OUR. The units of OUR are mg L^{-1} h^{-1}.

Example 8:

An experiment was then conducted to study the drop in dissolved oxygen concentration of an effluent with time using dissolved oxygen meter. The results of the experiment are shown below.

Time, min	1	2	3	4	5	6	7	8	9
DO, mg/L	6.37	6.12	5.94	5.74	5.56	5.37	5.18	4.97	4.82
Time, min	9	10	11	12	13	14	15	-	-
DO, mg/L	4.82	4.64	4.47	4.29	4.12	3.95	3.79	-	-

Compute OUR.

Answer:

The OUR graph is plotted and shown in Fig 8.1.

$$OUR = \frac{6.37-3.79}{15-1} \text{ mg } L^{-1} \text{ min}^{-1}$$

$$= 0.172 \times 60 \text{ mg } L^{-1} h^{-1}$$

$$= 10.32 \text{ mg } L^{-1} h^{-1}$$

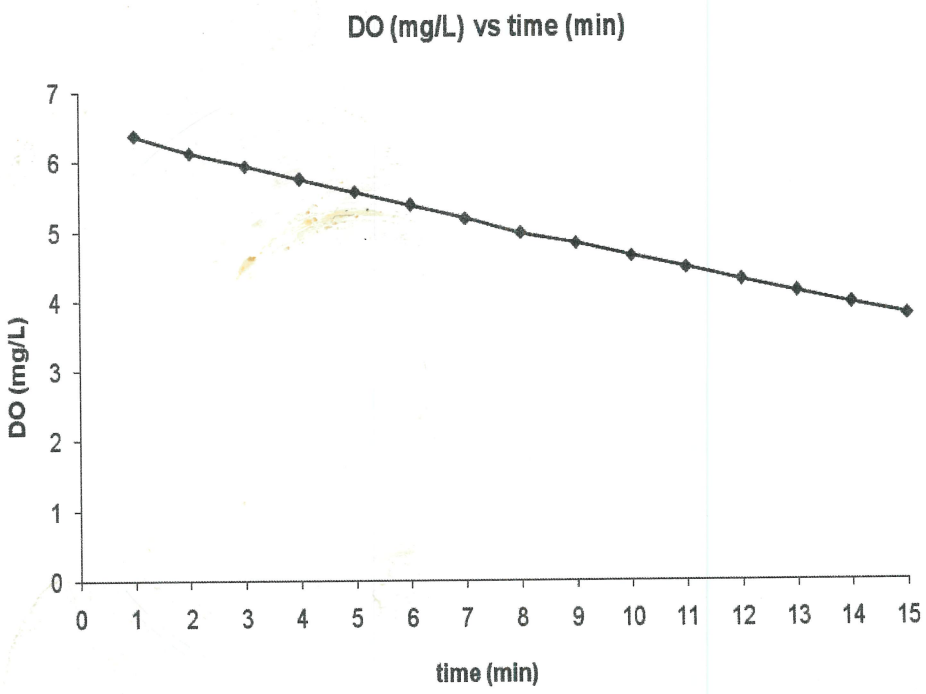


Fig 8.1: Graph of DO, (mg/L) versus time, (min)

8.8 Specific oxygen uptake rate (SOUR)

SOUR can be calculated simply by dividing the OUR by MLVS (in g/L).

SOUR = OUR/MLVSS

The units of SOUR are: mg $h^{-1}O_2$ / g MLVSS

Example 9:

What would be the SOUR if the mixed liquor volatile suspended solids concentration in example 5 was 3000 mg/L.

Answer:

Using the above formula:

$$SOUR = OUR/MLVSS$$

$$= \frac{10.32 \text{ mg } L^{-1} h^{-1}}{3 \text{ g } L^{-1}}$$

$$= 3.4 \text{ mg } h^{-1} O_2 / \text{g MLVSS}$$

8.9 Sludge wasting rate (WAS)

8.9.1 To calculate how much sludge is to be wasted (WAS) to achieve a desired MLSS concentration

The relevant formulas are:

Mass of WAS to be wasted, kg = Current SI, kg – Desired SI, kg

Volume of WAS to be wasted, m^3

$$= \frac{\text{Mass of WAS to be wasted, kg}}{\text{WAS concentration, mg/L}} \times 10^3$$

Example 10:

If the aeration tank volume = 200 m^3, calculate how much sludge is to be wasted from current MLSS concentration of 5000 mg/L to achieve a desired MLSS concentration of 3000 mg/L if WAS suspended solids concentration = 4000mg/L.

Answer:

V_R = 200 m^3

Current MLSS concentration = 5000 mg/L
Desired MLSS concentration = 3000 mg/L
WAS MLSS concentration = 4000 mg/L

Using the above formulas:
Mass of WAS to be wasted
= V_R (Current MLSS concentration-Desired MLSS concentration)/1000
= 200 (5000-3000)/1000
= 400 kg

$$\text{WAS volume to be wasted, } m^3 = \frac{\text{Mass of WAS to be wasted, kg}}{\text{WAS MLSS concentration, mg/L}} \times 10^3$$

$$= 400/4000 \times 10^3$$
$$= 100\ m^3$$

8.9.2 To calculate how much sludge is to be wasted (WAS) to achieve a desired sludge age

The relevant formulas are:

Mass of solids under aeration, kg

$$= \frac{V_R, m^3 \times \text{MLSS, mg/L}}{1{,}000}$$

$$\text{Sludge age, day} = \frac{\text{Mass of solids under aeration, kg}}{\text{Mass of sludge wasted per day, kg}}$$

Rearranging:

$$\text{Mass of sludge wasted per day} = \frac{\text{Mass of solids under aeration, kg}}{\text{Sludge age, d}}$$

But:

Mass of sludge wasted per day = WAS x Q_{WAS}

Note: WAS is sometimes denoted as VSS_{RAS})

Mass of solids under aeration = MLSS x V_R

Substituting:

$$WAS \times Q_{WAS} = \frac{MLSS \times V_R}{\theta_c}$$

Therefore:

$$Q_{WAS} = \frac{MLSS \times V_R}{\theta_c \times WAS}$$

Example 11:

With an aeration tank volume of 100 m^3, MLSS of 3000 mg/L and WAS concentration of 5000 mg/L, calculate how much sludge is to be wasted to achieve a desired sludge age of 15 d.

Answer:

V_R = 100 m^3

MLSS = 3000 mg/L

VSS_{RAS} (i.e. WAS concentration) = 5000 mg/L

Desired θ_c = 15 d

Using the above formula:

$$Q_{WAS} = \frac{MLSS \times V_R}{\theta_c \times WAS}$$

$$= \frac{3000 \times 1000}{15 \times 5000}$$

$$= 40 \text{ m}^3/\text{d}$$

8.9.3 To calculate how much sludge is to be wasted to maintain a certain sludge age if sludge withdrawal is made directly from the aeration tank

Neglecting the influent SS, the wasted sludge can be calculated from the equation:

$$Q_{WAS} = \frac{V_R}{\theta_c}$$

Example 12:

If the aeration tank is 2000 m^3 and the sludge age to be maintained is 20 d, how much sludge is to be wasted daily?

Answer:

$A_R = 2000 \text{ m}^3$

$\theta_c = 20 \text{ d}$

Using the formula $Q_{WAS} = \frac{V_R}{\theta_c}$

$$= \frac{2000}{20} \text{ m}^3/\text{d}$$

$$= 100 \text{ m}^3/\text{d}$$

Therefore excess sludge to be wasted is 100 m^3/d

8.9.4 To calculate how much sludge is to be waste to maintain a certain sludge age if sludge withdrawal is made from the RAS line

Neglecting the influent SS, the wasted sludge can be calculated from the equation:

$$Q_{WAS} = \frac{V_R \text{ x MLSS}}{\theta_c \text{ x } SS_{RAS}}$$

Note that in some references MLSS is denoted as X and SS_{RAS} as X_R.

Example 13:

If the aeration tank is 2000 m^3, mixed liquor suspended solids concentration is 3000 mg/L, the return sludge concentration is 1% and the sludge age to be maintained is 20 d, how much sludge is to be wasted daily?

Answer:

A_R = 2000 m^3
θ_c = 20 d
SS_{RAS} = 10,000 mg/L
MLSS = 3000 mg/L

Using the formula $Q_{WAS} = \frac{V_R \text{ x MLSS}}{\theta_c \text{ x } SS_{RAS}}$

$$= \frac{2000 \text{ m}^3\text{/d x } 3000 \text{ mg/L}}{20 \text{ x } 10,000 \text{ mg/L}}$$

$$= 30 \text{ m}^3\text{/d}$$

Therefore excess sludge to be wasted is 30 m^3/d

8.10 Sludge recycle rate (RAS)

8.10.1 To calculate how much sludge is to be recycled (RAS) to achieve a desired F/M ratio

The formula to calculate F/M ratio is:

$$\text{F/M} = \text{Food/Microorganism}$$

$$\text{F/M, d}^{-1} = \frac{\text{Q, m}^3\text{/ d x BOD, mg/L}}{\text{V}_R\text{, m}^3 \text{ x MLVSS, mg/L}}$$

Note that M, (i.e. the mass of microorganism to be maintained in the aeration tank) is equal to SI.

Example 14:

Calculate the RAS required in m^3/d if RAS concentration is 2% VSS, influent flow is 150 m^3/ d, influent BOD is 200 mg/L, and the desired F/M ratio is 0.5 d^{-1} (CAS).

Answer:

$$\text{F/M} = 0.5\ d^{-1}$$

$$\text{M} = \text{F}/0.5 = \frac{150 \times 200/1000\ \text{kg/d}}{0.5\ \text{/d}}$$

$$= 60\ \text{kg}$$

So we need to add 60 kg of microbes to the aeration tank daily. So the unit is kg/d.

RAS is 2% VSS [i.e. from SS test: 100 g of dried RAS weighs 5 g. When burnt at 550°C, 100 g of RAS weighs 3 g. So, from 100 g, (5-3 =2) 2 g is considered to be microbes. Hence, RAS is 2% microbes].

RAS to be fed into the aeration tank daily = 60 kg/0.02

= 3000 kg

So, RAS = 3000 kg/d
= 3000 x 1000/(24 x 60) g/min
= 2083 g/min

8.10.2 To calculate how much sludge is to be recycled (RAS) to achieve a desired MLVSS

The RAS rate can be determined by using the **solids balance equation** or sometimes called **mass balance method**. The solids balance equation is:

$$Q_{RAS} = \frac{Q, m^3/d \times MLVSS, mg/L}{VSS_{RAS}, mg/L - MLVSS, mg/L}$$

Where:

Q = influent flow rate
MLVSS = Mixed liquor volatile suspended solids
VSS_{RAS} = VSS of RAS

Example 15:

If the influent flow to the aeration tank is 8000 m^3/d and mixed liquor volatile suspended solids concentration is 2200 mg/L and return volatile solids concentration is 0.78%, calculate the sludge return rate.

Answer:

Q = 8000 m^3/d
MLVSS = 2200 mg/L
VSS_{RAS} = 0.78% = 7800 mg/L

(note: 1% = 10,000 mg/L)

Find sludge return rate (Q_{RAS})

Using the above formula:

$$Q_{RAS} = \frac{Q \times MLVSS}{VSS_{RAS} - MLVSS}$$

$$= \frac{8000 \times 2200}{7800-2200}$$

$$= 3140\ m^3/d$$

Therefore, RAS rate = 314 m^3/d

8.10.3 To calculate how much sludge is to be recycled (RAS) to achieve a desired MLSS

The recycle ratio (R) can be expressed as:

$$R = \frac{Q_R}{Q} = \frac{MLSS}{SS_{RAS}-MLSS}$$

Note that in some references MLSS is denoted as X and SS_{RAS} as X_R.

Knowing the influent flow, the SS concentration in return sludge and the MLSS concentration to be maintained in the aeration tank, the return sludge flow can be determined.

Example 16:

If the influent flow is 2000 m^3/d, mixed liquor suspended solids concentration to be maintained is 3000 mg/L and return sludge concentration is 1%, calculate the return sludge flow.

Answer:

$Q = 2000\ m^3/d$
$MLSS = 3000\ mg/L$
$SS_{RAS} = 1\% = 10{,}000\ mg/L$

Using the above formula:

$$R = \frac{MLSS}{SS_{RAS}-MLSS}$$
$$= \frac{3000}{10{,}000-3000}$$
$$= 0.43$$

$$Q_R = R \times Q$$
$$= 0.43 \times 2000\ m^3/d$$
$$= 857\ m^3/d$$

Therefore the return sludge flow (RAS) is 857 m^3/d

8.10.4 To calculate how much sludge is to be recycled (return activated sludge-RAS rate) using settelability consideration

Settleability is defined as the volume occupied by the sludge after settling for thirty minutes expressed in mL/L.
The formula to determine RAS rate (Q_{RAS}) is given by:

$$Q_{RAS} = \frac{Q,\ m^3/d \times SV_{30},\ mL/L}{1000 - SV_{30},\ mL/L}$$

Where:

Q_{RAS} = RAS rate
SV_{30} = Settled sludge volume

Example 17:

Calculate sludge return flow rate if the influent flow is 8000 m^3/d and sludge settled volume after 30 minutes is 275 mL/L.

Answer:

Q = 8000 m^3/d
Sludge settled volume = SV_{30} = 275 mL/L.

Using the formula:

$$Q_{RAS} = \frac{Q \times SV_{30}}{1000 - SV_{30}}$$
$$= \frac{8000 \times 275}{1000 - 275}$$
$$= 3035\ m^3/d$$

Therefore, RAS rate = 3035 m^3/d

8.11 Nutrient requirements

The **practical guide** for nutrient requirements is to provide a ratio of:

(i) 100BOD: 5N: 1P for a conventional activated sludge system (CAS)
(ii) 100BOD: 7N: 3P for a young sludge (such as during IETS commissioning) or a BOD shock loading
(iii) 100BOD: 3N: 0.5P for an extended aeration activated system (EAAS).

Example 18:

Calculate the nutrient (N and P) required if the influent to a CAS has a flowrate of 100 m^3/d, BOD of 500 mg/L and NH_3 of 5 mg/L. The compound used for supplying N is UREA (46% N) and for P is Trisodium Phosphate (90% P).

Answer:

Part A: N requirement

(i) $N_{calculated} = \frac{5 \times 500}{100}$ mg/L = 25 mg/L

N actually required = N calculated - N in influent

(ii) N actually required = 25-5 = 20 mg/L

N actually required is also known as N shortfall

(iii) Weight of N actually required =

$$\frac{\text{N shortfall, mg/L x flow rate, } m^3/d}{1000}$$

$$= \frac{20 \times 100}{1000} \text{ kg/d}$$

$$= 2 \text{ kg/d}$$

(iv) To determine weight of a UREA $\{CO(NH_2)_2\}$ containing the weight of N actually required (2 kg/d)

$$\text{UREA kg/d} = \frac{\text{Weight of N actually required x N atomic weight ratio}}{\text{Concentration of N in UREA (as a \%)}}$$

UREA has a chemical formula: $CO(NH_2)_2$

Atomic wt. of C = 12 x 1 = 12

Atomic wt. of O = 16 x 1 = 16

Atomic wt. of N = 14 x 2 = 28

Atomic wt. of H = 1 x 4 = 4

Total atomic wt. of UREA = 60

Atomic wt. ratio of N/UREA = 60/28 = 2.14

Given that N content in UREA = 46%

Therefore the actual UREA required = $\frac{2 \text{ kg/d} \times 2.14}{0.46}$

= 9.3 kg/d

Phosphate requirement

(i) $P_{calculated} = \frac{1 \times 500}{100}$ mg/L = 5 mg/L

P actually required = P calculated since the influent does not contain any P

(ii) Weight of P actually required =

$$\frac{\text{P actual, mg/L x flow rate, m3/d}}{1000}$$

$$= \frac{5 \times 100}{1000} \text{ kg/d}$$

$$= 0.5 \text{ kg/d}$$

(iii) To determine weight of Trisodium Phosphate-TSP (Na_3PO_4) containing the weight of P actually required (0.5 kg/d)

If we were to do the same calculation for TSP as we did for N in the above section, we will arrive at the conclusion that:

Atomic wt. ratio of P/TSP = 5.29

Given that P content in TSP = 90%

Therefore the actual UREA required = $\frac{0.5 \text{ kg/d} \times 5.29}{0.90}$

= 2.9 kg/d

8.12 Summary of formulae for BP computations

Table 8.1 gives a summary of formulae that are commonly used for computations in biological treatment processes (BPs).

Table 8.1: Summary of typical formula for BP computations

Computation for	Formula
Average daily flow	ADF = $\frac{\text{Totalizer reading}_2 - \text{Totalizer reading}_1}{T_2 - T_1}$
Detention time	DT = $\frac{V}{Q}$
SS_{RAS} or VSS_{RAS}	1% = 10.000 mg/L
Solids inventory	SI, kg = $\frac{V_R, m^3 \times MLVSS, mg/L}{1{,}000}$
Sludge volume index	SVI, mL/g = $\frac{SV, mL/L \times 1000}{MLSS, mg/L}$
Sludge age	$\theta_c = \frac{MLSS, mg/L \times V_R, m^3}{WAS, mg/L \times Q_{WAS}, m^3/d}$
Oxygen uptake rate	Gradient of plot a graph of O_2, mg/L versus Time, min. Units of OUR: mg L^{-1} h^{-1}.
Specific oxygen uptake rate	SOUR = OUR/MLVSS Units of SOUR: mg $h^{-1}O_2$ / g MLVSS
Sludge wasting rate directly from aeration tank	$Q_{WAS} = \frac{V_R}{\theta_c}$
Sludge wasting rate from recycle line	$Q_{WAS} = \frac{V_R \times MLSS}{\theta_c \times SS_{RAS}}$
Food to Microorganism ratio	F/M, d^{-1} = $\frac{Q, m^3/d \times BOD, mg/L}{V_R, m^3 \times MLVSS, mg/L}$
Return or recycle ratio	R = $\frac{MLSS}{SS_{RAS}-MLSS}$
Chemical compound for supplying N or P	Chemical, kg/d = $\frac{\text{Weight of N or P actually required} \times \text{N or P atomic weight ratio}}{\text{Concentration of N or P in chemical compound (as a \%)}}$

Return activated sludge rate	$Q_{RAS} = \frac{Q \times MLVSS}{VSS_{RAS} - MLVSS}$
Return activated sludge rate	$Q_{RAS} = \frac{Q \times SV_{30}}{1000 - SV_{30}}$
Mass WAS to be wasted	WAS to be wasted, kg = Current SI, kg – Desired SI, kg
Volume WAS to be wasted	WAS to be wasted, m^3 $= \frac{\text{Mass of WAS to be wasted, kg}}{\text{WAS concentration, mg/L}} \times 10^3$

8.13 From the perspective of the DOE officer/inspector

As a DOE officer/ inspector you understand that:

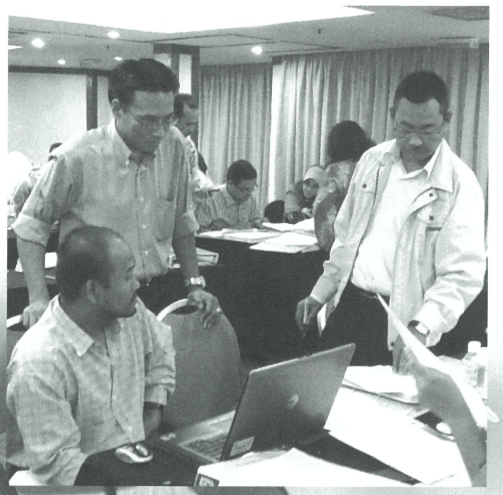
(i) Operating an IETS-BP requires **dynamic interaction** by the supervisor/ operator to respond to the changing situations in the IETS

(ii) Routine **computations** of certain operational parameters need to be performed and operational actions taken based on the results of the computations

(iii) You need to examine the **records** maintained by the IETS team to ensure the IETS is being operated according to sound engineering practice based on the results of the computations.

CHAPTER 9:

HOW TO CONTROL BIOLOGICAL TREATMENT PROCESSES







MODULE 9:

HOW TO CONTROL BIOLOGICAL TREATMENT PROCESSES

PART A: CONTROLLING THE ACTIVATED SLUDGE SYSTEMS

The activated sludge systems include all modifications to the basic activated sludge process such as: conventional activated sludge (CAS) system, extended aeration activated sludge (EAAS) system, sequencing batch reactor (SBR), membrane bioreactor (MBR), oxidation ditch (OD) and selector activated sludge system (SAS). Most of the **process control methods** discussed in this Module are applicable to these different versions of the activated sludge system.

9.1 Process control methods

There are primarily **five different ways** to control an activated sludge (AS) system. Each of the way requires certain tests to be performed to obtain the relevant information which will be used to control the system. The five process control methods are:

(i) Constant solids
(ii) Constant F/M ratio
(iii) Constant sludge age
(iv) Constant SVI
(v) Constant oxygen uptake rate

Another additional tool which can be utilized to assist the IETS supervisor/ operator in the operation of the IETS is microscopic microbiological examination. This useful tool is yet to be fully appreciated by IETS professionals in the field of IETS operation in Malaysia. As an IETS operator/supervisor the main objective is to operate the IETS-BP in an **optimal condition** to produce **compliant effluent** all the time. The operator would need to make use of one or a number of the above control methods to control the IETS. Through experience operating the IETS, the operator would choose the method which would work best for his situation.

9.2 Constant solids (MLVSS) method

The term solids refers the microorganisms in the aeration tank. Control an activated sludge process (AS) using "constant solids method" means that an optimum concentration of mixed liquor volatile suspended solids (MLVSS) is decided and this concentration is to be maintained. This method of control of AS system requires information on the **MLVSS** which gives the best quality of final effluent for your IETS. The information on what the best MLVSS is for your IETS is usually obtained by **trial and error**. Once this value of MLVSS has been obtained, you as an IETS supervisor/operator will need to strive to maintain it by performing **sludge wasting several times daily**. The calculation for the amount of sludge to be wasted to achieve a desired MLSS concentration has been illustrated in Example 10 in Chapter 8. MLVSS will not remain constant but will **vary** throughout the day, across the aeration tank and with influent flow changes in return sludge flow (RAS) and concentration. To obtain **representative sample** of MLVSS it is recommended that all samples are taken at least from **three locations** in the aeration tank. If there are several compartments in the aeration tank, each compartment must be sampled. In a long, narrow tank, samples should be taken close to the inlet, outlet and in the middle of the tank. Samples should be taken at the same locations at the same time each day.

Typical ranges of MLVSS are shown in Table 9.1

Table 9.1: Typical ranges of MLVSS for different types of AS system

Type of AS system	MLVSS range, mg/L
CAS	1600-2400
EAAS	3200-4800

9.2.1 From the perspective of the DOE officer/inspector

You understand that the workhorses for biodegradation process are the microorganisms. Sufficient number of microorganisms must be maintained within the aeration tank relative to food available to ensure complete biodegradation of the organic matter. Your task is to check that the **microorganism concentration** represented by the MLVSS is maintained within the recommended range.

9.3 Constant food to microorganism (F/M) ratio method

F/M expresses the **amount of food** available to the **number of microorganisms** in the aeration tank. Insufficient amount of food or overdose of it will lead to **settling problems** in the clarifier.

Food is represented by the **amount of BOD or COD** while the number of microorganisms by the **MLVSS**. COD test gives results within **4 hours** while BOD test takes **five days**. You can choose either BOD or COD to calculate the F/M ratio, but once you have chosen which one to use, you should stick to it for comparative purposes.

The following **data** are required for the computation of F/M ratio.

- COD, of influent to the aeration tank, mg/L
- Q, flowrate of influent or effluent, m^3/d
- SI, solid inventory in the aeration tank, kg

Typical F/M ratios are shown in Table 9.2.

Table 9.2: Typical ranges of F/M ratio for different types of AS system

Type of AS System	*F/M, kg BOD per day/kg MLVSS under aeration	*F/M, kg COD per day/kg MLVSS under aeration
CAS	0.1 to 0.5	0.15 to 0.7
EAAS	0.05 to 0.1	< 0.15

* (Note: Units of F/M can be reduced to d^{-1})

The appropriate F/M for any particular IETS depends on several factors such as: type of system; desired effluent quality and the individual **characteristics** of the effluent. The best F/M can be arrived at through **experience and experimenting**. F/M ratio can be changed by adjusting the amount of solids in the aeration tank (SI) in relation to the food. The amount of solids in turn depends on the **sludge wasting rate**. The calculation for the amount of sludge to be wasted have been illustrated in Examples 10,11,12 and 13 in Chapter 8.

9.3.1 From the perspective of the DOE officer/ inspector

You understand that too much or too little food (i.e. extreme values of F/M) will have negative effects on **settling characteristics** of the sludge which will in turn affect **effluent quality**. Your task as the DOE officer/ inspector is to find out from the industry's IETS team and check industry PM records that the F/M ratio is maintained within the optimal range for the IETS.

9.4 Constant sludge age (θ_c) method

Sludge age (θ_c) is also known in the past as **mean cell residence time (MCRT)** or **solids retention time (SRT)**. Sludge age is the **length of time** the average microorganism remains in the treatment system.

As an IETS operator, your task is to determine the sludge age that is most effective (i.e. that produces the best final effluent quality) for your IETS and to strive to maintain it. This can be done through **trial and error** basis by operating your IETS at different sludge age and monitoring the effluent quality.

Typical sludge age ranges being used to operate different types of AS systems are shown in Table 9.3.

Table 9.3: Typical ranges of sludge age for different types of AS system

Type of AS system	θ_c, d
CAS	5 to 15
EAAS	20-35

The calculations for the sludge age have been illustrated in Example 6 and 7 in Chapter 8. Example 11,12 and 13 show how sludge wasting rate can be determined to maintain a certain sludge age.

F/M ratio and the sludge age are **interrelated**, changing one will change the other. F/M and sludge age can be changed by **increasing or decreasing** the amount of **sludge wasted**. As an IETS operator your task is to determine the optimum F/M ratio and sludge age for your IETS and to maintain them.

Are there **practical signs** (tell-tale signs) that indicate if the F/M ratio is too high or sludge age too short (young sludge)?

Some of the tell-tale signs that may be used to indicate that F/M ratio is **too high** or the sludge is **too young** are:

(i) Dissolved oxygen in the aeration task is low. It is **difficult to maintain** a minimum DO level

(ii) Sludge in the aeration tank is **light brown** and **settles slowly**

(iii) Specific oxygen uptake rate (SOUR) is **above normal**
(iv) Thick **foam** appears on the aeration tank

9.4.1 From the perspective of the DOE officer/ inspector

You understand that sludge age is an important parameter which should be monitored and maintained within the recommended range to ensure the microorganisms have **sufficient contact time** to biodegrade the organic matter in the IETS. Too high or too low θ_c may produce adverse impacts on the microbiological processes hence the quality of the final effluent. You should enquire and check factory records to see that θ_c is being maintained within the recommended range.

9.5 Constant sludge volume index (SVI) method

Control of activated sludge process by using SVI requires the IETS technicians to perform **sludge settling test** on a daily basis to:

(i) Make **visual observation** on the floc and blanket formation
(ii) Determine SVI

SVI tests are performed on mixed liquor samples (i.e samples from the aeration tank). With experience the **quality of the sludge** can be judged by making observations on the floc and blanket characteristics and color of the sludge. From the SVI readings and effluent quality one would note the optimum SVI for the IETS and one would then strive to maintain it. If SVI is increasing, you would want to increase the solids level needs to be increased by lowering the sludge wasting rate. On the other hand, if SVI is decreasing (< 50) there is an impending problem with **pinpoint floc** carryover in the clarifier overflow. This is the result from the phenomenon of **sludge settling too fast**. In this situation, you should decrease the sludge age should be decreased by wasting more.

The SVI calculation has been illustrated in Example 4 in Chapter 8 while the calculation for sludge recycle rate (RAS) to maintain a desired SVI in Example 17. The SVI values and the sludge settling characteristics are summarized in Table 9.4.

Table 9.4: SVI values and the sludge settling characteristics

SVI, mL/g	Settling characteristics
< 50	Sludge settles extremely well
50-100	Good sludge settling property
100-150	Acceptable sludge settling property
. 150	Bulking sludge

The objective is to maintain a SVI for your IETS in the recommended range of 50 to 100 mL/g.

9.5.1 From the perspective of the DOE officer/ inspector

Although SVI test is simple, easy to perform and empirical in nature, it has been universally utilized by the IETS personnel in the operation of biological treatment processes (BPs). Based on the SVI information you would know how the **clarifier** will perform and hence how it would affect the performance of the entire IETS. As a DOE officer/inspector you should check the PM records to see if the SVI has been maintained within the recommended range, hence produce quality effluent from the IETS.

9.6 Constant specific oxygen uptake rate (SOUR) method

Oxygen uptake rate (OUR) is the **amount of oxygen** used by the microorganisms per unit time expressed as mg/L per hour. The OUR reflects how active the microorganisms are in the aeration tank which also reflects how fast the

biodegradation activity of the organic matter is occurring. SOUR is the specific oxygen uptake rate is computed by dividing OUR by the concentration of microorganisms. The calculations on OUR and SOUR have been illustrated in Examples 8 and 9 in Chapter 8.

A typical **rule of thumb** indicating an optimum range of SOUR is 8 to 20 mg of O_2 per hour per g of MLVSS.
What happens if the SOUR is outside this range?

(i) SOUR > 20 mg of O_2 per liter per hour per g MLVSS.

If SOUR is **above** the optimal range it means that the F/M ratio is **increasing** which in turn means that there is **too much food** and **too few microorganisms**. This situation can happen is BOD load to the aeration tank is increased (see the numerator in the F/M ratio term) or there is too much wasting (see the denominator in the F/M ratio term). Too much wasting means the **sludge is too young** which leads to **light weight sludge** which does not settle easily. Young sludge when recycling to the aeration tank requires more aeration.

As an IETS operator what do you do when you notice a problem with the SOUR being outside the optimal range? As an immediate measure you can **increase the aeration time**. On a longer time, you should **increase** the sludge age and MLVSS concentration in the aeration tank by **decreasing** sludge wasting and increasing the rate of sludge return.

If you experience frequent problems with high SOUR, you should discuss with your IETS team which should include a representative from the engineering department to look into possible solutions such as: (i) To **redistribute** the load or if problem exists (ii) To provide additional time in the **reaeration tank** before recycling the sludge to the aeration tank. Engineering department personnel should be involved because the possible solutions may entail substantial IETS operational changes or investment of structural components.

(ii) SOUR < 8 mgO_2 per hour per g MLVSS

If **SOUR is low**, it means **F/M ratio is decreasing**. It also means that there is **insufficient food** (look at the numerator in the F/M term) which will create a problem with **the sludge that settles too quickly**. **Pinpoint floc and straggler floc** will develop resulting in an increase in suspended solid in the final effluent. If this condition persists you can address it by **increasing the wasting rate**.

What could happen if the F/M ratio is within the acceptable range but the SOUR is low? Your IETS could be experiencing a **toxic load** in the incoming effluent which is depressing the microbiological activity of the microorganisms.

9.6.2 Respirometry

Nowadays, respirometric measurements can be made by using respirometers which can be operated in **different modes** to suit measurement objectives. The **bioactivity information** acquired by means of respirometry technique can be utilized for several purposes including effluent treatability studies, IETS process control, optimization and diagnosis. **On-line respirometers** which use mixed liquor from an operating IETS yield oxygen uptake characteristics for the IETS under actual operating conditions. Combined with software capabilities, useful calculations, data analysis and different types of **respirograms** can be automatically generated for process management purposes.

9.6.3 From the perspective of the DOE officer/inspector

As a DOE officer/ inspector you understand that SOUR test is a simple, practical tool to monitor a biological treatment process (BP). It provides useful information to the IETS supervisor/operator on how well the **biodegradation process** is occurring in the aeration tank. Additionally, it serves as an early warning system to indicate onset of upset conditions,

with which the IETS personnel can take proactive measures to address the situation. You should check factory records and discuss with the IETS supervisor/operator to impart to them the importance of SOUR monitoring in IETS operation.

9.7 Microscopic microbiological examination

Although microbiological examination is not exactly a method to control an IETS-BP, it can provide a wealth of information that is useful for the control of the activated sludge systems. We are interested in identifying the presence or absence of **different kinds of microorganisms** in the IETS because each of these types of microorganisms **thrives best** under certain conditions, so their presence or absence can be related to the degree of treatment, hence the **efficiency** of the IETS.

From Chapter 5 you understand that the different kinds of microorganisms found in the activated sludge process are:

- Bacteria
- Protozoa
- Rotifers
- Filamentous organisms (fungi or bacteria)

The most important group of microorganisms is the **bacteria** which stabilize most of the **organic matter** contained in the effluent. Many types of bacteria are found in the biological reactor of the activated sludge process. The dominant type of bacteria which will populate in the tank is determined by the **nature of organic matter** in the effluent and in the way the **IETS is operated**. Apart from stabilizing the organic matter, bacteria are also responsible for **floc formation** which helps in **sludge settling**.

In the activated sludge process, **protozoa** are also important microorganisms as they can be used as an **indicator** of the efficiency the treatment process. Although the protozoa themselves do not stabilize the organic matter in the effluent, they **feed on the bacteria** and this helps **clarify the effluent**. Two types of **ciliated protozoa**

are found in the activated sludge process: **free swimming** ciliate and **stalked ciliate**. The presence of ciliated protozoa is indicative of an **efficient treatment process**. If there is a high bacteria population, there will be a dominance of free swimming ciliates. However the population of stalked ciliates will increase as the food level is reduced.

Rotifers are not commonly found in an activated sludge process. Their presence is indicative of a condition of very **low F/M ratio** or **high sludge age (old sludge)**. **Filamentous organisms** are **problem organisms** in an activated sludge which cause problem of **sludge settling**. The term **'sludge bulking'** refers to the condition where sludge does not settle resulting in carry over of solids in the clarifier effluent. The predominance of filamentous organisms which can be either bacteria or fungi, is usually the result of **low pH, low DO, or low nutrient levels**.

9.7.1 From the perspective of the DOE officer/inspector

As a DOE officer/inspector, you understand that by having knowledge of the microorganisms in the activated sludge of the IETS, the process can be controlled.

Daily observation of the microorganisms in the activated sludge sample will help the IETS supervisor/operator detect the changes in the number of stalked or free swimming ciliates or the presence of rotifers. Based on the information appropriate decision to change the **solids level** in the aeration tank can be made.

For example, if it is observed that there is a decrease in the number of free swimming ciliates and a corresponding increase in the number of stalked ciliates, it indicates low food concentration (low F/M or high sludge age), hence the solids level can be lowered by increasing sludge wasting.

As a summary, we can say that the **bacteria biodegrade** the organic matter and the **protozoa feed on the bacteria** and help clarify the effluent.

Process stability is indicated by the **relative number of stalked and free swimming ciliates**.

9.8 Summary of methods for controlling an activated sludge process

The discussions on the five methods available for the control of an activated sludge process are summarized in Table 9.5 for easy reference.

Table 9.5: Summary of methods to control activated sludge process

Control method	Information and data required	Details of operator's task for controlling the activated sludge process using the chosen control method
Constant solids	(i) By trial and error determine the MLVSS which gives the best quality of final effluent. (ii) Data required: MLVSS.	(i) Maintain MLVSS by performing sludge wasting several times daily.
F/M ratio	(i) By trial and error determine the optimum F/M **ratio** which gives the best quality of final effluent. (ii) Data required: - COD of influent to the aeration tank, mg/L - Q, flowrate of influent, m^3/d - SI, solids inventory in the aeration tank, kg $F/M = \frac{(COD, mg/L) \times (Q\ m^3/d)}{1{,}000 \times SI, kg}$	(ii) Maintain F/M ratio by changing sludge wasting rate in relation organic load

Sludge age (θ_c)	(i) By trial and error determine the optimum sludge age which gives the best quality of final effluent. (ii) Data required: - MLVSS in the aeration tank - kg VSS in waste sludge/d - kg VSS in effluent/d $\theta_c, d = \frac{\text{kg MLVSS}_{\text{in the aeration tank}}}{[\text{kg VSS}_{\text{in waste sludge}}/d] + [\text{kg VSS}_{\text{in effluent}}/d]}$	(i) Change sludge age by increasing or decreasing the amount of sludge wasted.
Microbiology	(i) Daily observation of the number of stalked or free swimming ciliates or the presence of rotifers.	(i) If there is a decrease in the number of free swimming ciliates and a corresponding increase in the number of stalked ciliates, lower the solids level by increasing sludge wasting.
Sludge Volume Index (SVI)	(i) Determine the optimum SVI which gives the required effluent quality (ii) Information required: - SV_{30}, mL/L - MLSS, mg/L $SVI = \frac{SV_{30}\ \text{mL/L} \times 1000}{\text{MLSS, mg/L}}$	(i) If SVI is increasing, increase the solids level and sludge age by lowering the sludge wasting rate. (ii) If SVI is decreasing decrease the sludge age by wasting more.

Table 9.5: Summary of methods to control an activated sludge process

Specific oxygen uptake rate (SOUR)	(i) Information required: OUR and MLVSS (ii) Optimum range of SOUR: is 8 to 20 mg of O_2 per hour per g of MLVSS SOUR= OUR/MLVSS	(i) If SOUR > 20 $mg_{of}O_2$ per liter per hour per g MLSS, increase the aeration time. On a longer time, increase the sludge age and MLVSS by decreasing sludge wasting and increasing the rate of sludge return. (ii) If SOUR < 8 mgO_2 per hour per g MLVSS, increase the wasting rate.

PART B- SECONDARY CLARIFIERS -SLUDGE RETURN AND SLUDGE WASTING

9.9 Purpose of Clarifiers

Clarifiers serve a **double purpose** in an activated sludge (AS) system namely, to **clarify the effluent** and to provide **concentrated sludge** for use as **sludge return**. Over the years operators of activated sludge systems have gained valuable experience in the operation of clarifiers. To ensure smooth and effective operation of clarifier, a set of **operating procedure** has been developed as follows:

(i) Using the SI data, calculate **sludge age daily**. If necessary make necessary adjustments to the waste activated sludge (WAS).

(ii) Check the **sludge blanket**. If necessary adjust return activated sludge (RAS).

(iii) Determine **SVI**. If there are any changes, take a microbiological sample. Observe for changes in the number of stalked, free-swimming ciliates and filamentous organisms. If SVI deterriorates, change sludge age.

(iv) Check **F/M ratio**. Because the BOD or COD of the influent is fluctuating, use the average value of samples take over several days. Compare the F/M ratio with that obtained previously and observe the change.

(v) Determine the **oxygen uptake rate** if it is increasing or decreasing, change the sludge age accordingly.

9.10 Sludge return

Why do we practice **sludge return**? Sludge return is practiced for two purposes:

(i) To **remove sludge** from the clarifier.

(ii) To ensure **sufficient microorganism concentration** in the aeration tank so that a desirable F/M ratio can be maintained for optimal treatment efficiency.

9.11 Determination of return activated sludge (RAS)

How do you determine the return sludge flow rate (RAS)? It is based on consideration of the **solids level** in the system. Typically, there are three (3) ways to do this, namely

(i) **Sludge depth** consideration
(ii) **Solids balance** equation
(iii) **Settleability** consideration

In the first method you need to observe the **depth of the sludge blanket** regularly. A rule of thumb which is widely practiced is to maintain the sludge in the **bottom quarter** of the clarifier. However you should determine what is best for your IETS by experience.

Measurement of sludge blanket should be conducted at the **same time each day** preferably during the **peak flow** where the clarifier is operating with the **maximum loading rate.** Sludge depth can be measured via several ways, namely by using:

(i) Sludge judge
(ii) Sludge gun
(iii) Sludge depth meter

Based on the daily measurement of the sludge blanket, you can adjust the RAS rate accordingly. It is advisable that RAS adjustment is made **several times daily.**

The second way to determine the RAS rate is by using the **solids balance equation**. The solids balance equation. The use of this method to calculate RAS has been illustrated in Example 14 and 15 in Chapter 8.

The third way of determining the return sludge rate is by **settleability consideration**. Settleability is defined as the volume occupied by the sludge after settling for thirty minutes expressed in mL/L. The use of this method to determine RAS has been illustrated in Example 16 in Chapter 8.

The difficulty with the third method of determining return sludge flow is the settling condition during the settleability test is not exactly similar with the condition in the clarifier, hence the data obtained may not be representative.

For general information, **typical values of solids** in conventional activated sludge process are:

MLSS	=	2000 – 2500 mg/L
MLVSS	=	1500 – 2000 mg/L
SS_{RAS}	=	6000 – 8000 mg/L
VSS_{RAS}	=	4500 – 6000 mg/L

9.12 Summary or methods for determining return sludge flow (RAS)

The different methods for determining the return sludge flow (RAS) are summarized in Table 9.6.

Table: 9.6: Summary or methods for determining return sludge flow (RAS)

Method of control	Information required	Operator's task
sludge depth consideration	(i) Observe or measure the depth of the sludge blanket regularly. (ii) A rule of thumb: maintain the sludge in the bottom quarter of the clarifier.	(i) Adjust the RAS rate made several times daily according to the sludge depth
solids balance equation	(i) Data required: - MLVSS, mg/L - Q, m^3/d - VSS_{RAS}, mg/L $Q_{RAS} = \frac{Qx\ MLVSS}{VSS_{RAS} - MLVSS}$	(i) Compute the RAS from the relevant information and adjust it accordingly
settleability consideration	Data required: - SV_{30} - Q, m^3/d - $Q_{RAS} = \frac{Q\ x\ SV_{30}}{1000 - SV_{30}}$	(i) Compute the RAS from the relevant information and adjust it accordingly

9.13 Sludge wasting

Why do we do sludge wasting? We perform sludge wasting to:

(i) **Get rid** of the sludge
(ii) **Maintain desirable sludge concentration** in the aeration tank

How do we decide how much sludge to waste? Typically, there are three methods to determine sludge wasting rate, namely:

(i) By maintaining a **constant MLVSS**
(ii) By maintaining a **constant F/M ratio**
(iii) By maintaining a **constant sludge age**

9.13.1 By maintaining a constant MLVSS

The first method is by **maintaining a constant MLVSS**. This is **the simplest method** of determining how much sludge to waste. By **experience** you would determine at what level of MLVSS gives the **best performance** for your IETS and you then strive to maintain that level. From your MLVSS level, if it increases you would waste more until the level drops and conversely if the level falls you would waste less until the level comes back to the desired value. The calculation involved in this method od sludge wasting has been illustrated in Example 10 in Chapter 8 (this example uses MLSS instead of MLVSS).

What are the advantages and disadvantages of this method of controlling sludge wasting rate?

The advantages include: **simplicity** and **minimum laboratory test** required.

The disadvantages include: **changing MLVSS concentration** throughout the day and ignoring of F/M ratio.

What happens if the organic load of the influent is increasing over the previous day and the IETS supervisor/ operator is controlling sludge wasting rate by the first method?

9.13.2 By maintaining a constant F/M ratio

The second method of process control is by **maintaining a constant F/M ratio**. In this method, you would **observe the organic load** (by observing the COD of the influent) and you would decrease or increase MLVSS accordingly (by wasting more sludge or less).

Typically, activated sludge process is operated with a F/M ratio range as follows, based on COD:

CAS: 0.15 to 0.7 d^{-1}; EAAS: < 0.15 d^{-1}

You would determine what F/M ratio is best for your IETS and try to maintain it. The disadvantage about this method of control is you would need to have **advanced information** of the incoming organic load in order to determine the sludge wasting rate.

9.13.3 By maintaining a constant sludge age

The third method of controlling sludge wasting rate is by **maintaining a constant sludge age** that has been found to be effective for your IETS .To control sludge wasting by this method you need to **calculate sludge age**. For Q_{RAS} calculation you need following information:

- Aeration volume (V_R)
- MLVSS
- Sludge age
- Solids concentration in wasted sludge (VSS_{WAS})
- Solids concentration in clarifier effluent (VSS_{eff})
- IETS influent flow (Q)

The information required from **lab analysis** is the concentration of VSS in the mixed liquor, in the effluent and in the wasted sludge. The rest of information is easily available, but you need to fix your desired sludge

age. Examples of calculations involved in the control of wasting by this method have been illustrated in Example 11 and 12 in Chapter 8.

9.14 Summary of methods to determine sludge wasting rate

Table 9.7 summarizes the different methods available for determining sludge wasting rate (Q_{WAS}).

Table 9.7: Summary of different methods for determining sludge wasting rate (WAS)

Method of determining sludge wasting rate	Information required	Operator's task
Maintaining a constant MLVSS	(i) By experience determine the MLVSS level that gives the best final effluent. (ii) Data required: MLVSS	(i) If MLVSS level increases, waste more until the level drops and conversely if the level falls, waste less until the level comes back to the desired value.
Maintaining a constant F/M ratio	(i) Observe the organic load by observing the COD of the influent) (ii) Typical F/M ratio ranges between 0.15 to 0.7.	(i) Decrease or increase MLVSS accordingly by wasting more sludge or less.

Maintaining a constant sludge age	(i) By experience determine the sludge age that gives the best final effluent (i) Data required: - VSSmixed liquor, - VSSeffluent - VSSwasted sludge - aerator volume - Q	(i) Calculate sludge age (ii) Calculate sludge wasting rate

9.15. Sludge wasting procedure

How do you do sludge wasting? It is important to remember that since we are working with a **biological system** it is advisable to do any change **gradually**. The rule of thumb is not to change the wasting rate **more than 10%.** When you make any change you should record the result on the IETS performance to ensure that you are on the right track. If the IETS has shown improvement in performance, you should maintain the sludge wasting rate for about **three days** to make sure of the results. If you are wasting a certain amount each day, the best way is to do **frequent or continuous wasting** preferably at the minimum once per shift.

9.16. How to control the SBR

SBR system is a modification to the basic activated sludge process, but essentially, similar microbiological processes are occurring in the system. The SBR is operated under **nonsteady conditions** where all the processes of aerobic biodegradation and solids clarification are occurring in the same tank. Another difference between the SBR and the conventional activated sludge process is that there is **no return activated sludge (RAS)** in the SBR system. The SBR operation consists of repetition of a cycle which includes five separate steps: feed, react, settle, draw and idle. All process control parameters discussed in the preceding paragraphs are applicable to SBR systems.

In the operation of SBR systems, some additional points to note are given below.

(i) An operational strategy which is important to all biological treatment processes (BP) is the **on line monitoring of dissolved oxygen** using DO probes to control the aeration-blower run time during the cycle, which optimizes aeration requirements and in turn reduces the energy cost of aeration.

(ii) As discussed in section 6.11 (Table 6.8), for carbonaceous BOD removal, **ORP** should be monitored and maintained within the range of 50 mV to +250 mV.

(iii) As with any AS process, **sludge wasting** is the main operational tool to control the microorganism population size and sludge age, hence the effluent quality. Sludge wasting should occur during the **idle cycle** to provide the highest concentration of MLSS

(iv) Additional parameter which may need to be monitored is **alkalinity** especially if nitrification is expected (for example, effluent containing nitrogen from fertilizer manufacturing industry).

9.17 From the perspective of the DOE officer/ inspector

As a DOE officer/inspector you understand that:

(i) There are established methods to monitor the **health status** of biological treatment processes (BPs) which have been long practiced by IETS professionals worldwide

(ii) The PM parameters need to be monitored on a **routine basis** to ensure signs of onset of process upsets are captured so that corrective actions are taken before process failure occurs

(iii) The PM procedure needs to be **institutionalized** within the industry in order to cultivate it as a culture in IETS operation

(iv) PM parameters have well defined **acceptable ranges** which make them practical operational guides for IETS operators

(v) You need to find out and **check records** of PM kept by the industry and ensure the PM parameters are maintained within the recommended ranges.

PART C - HOW TO CONTROL OTHER BIOLOGICAL TREATMENT PROCESSES

9.18 How to control the ponding systems

The ponding systems include the stabilization ponds which may be anaerobic, facultative or aerobic in characteristic. In these systems **natural biodegradation processes** are occurring without direct intervention by the IETS supervisor/operator. Substantive process control is **not applicable** to the ponding systems which by en large depend on the natural processes without inputs from the IETS personnel. However, since ponding systems also rely on biological processes to biodegrade the organic matter present in the effluents, **minimal process monitoring** involving the monitoring of dissolved oxygen (for aerobic systems), nutrients, biochemical and chemical oxygen demands, sludge depth, pH, volatile fatty acids and alkalinity (for anaerobic systems) is necessary.

9.19 How to control the trickling filter and rotating biological contactor

The trickling filter (TF) and rotating biological contactor (RBC) are attached growth systems which are normally used as "roughing/pretreatment" processes to reduce the organic load to the subsequent process, such as the activated sludge system. Most of the **process control parameters** discussed in Part A of this Module are applicable to the TF and RBC systems.

9.20 How to control the upflow anaerobic sludge blanket (UASB) process

Anaerobic biological treatment of **high-strength organic effluents** is a proven technology that has been widely accepted. UASB uses an **anaerobic process** whilst forming a blanket of high concentration of immobilized sludge granules suspended in the tank. Being an anaerobic process, the discussion on process control parameters for activated sludge systems is not applicable to UASB systems. In order to ensure

proper operation and control of UASB process thorough monitoring of anaerobic process parameters is essential. The relevant parameters include the following:

(i) Parameter to measure the organic load and overall UASB efficiency, such as BOD or COD
(ii) pH
(iii) Temperature
(iv) Alkalinity
(v) Volatile fatty acids (VFAs)
(vi) Oxidation reduction potential (ORP)
(vii) Zone settling velocity
(viii) Biogas production

Some additional explanatory notes on certain concepts relevant to the operation of UASR process which have not been discussed in previous paragraphs are given below. Alkalinity can be understood to express the capacity of an effluent to neutralize acids hence **resist pH change**. This capacity is dependent on the concentration of carbonate, bicarbonate, and hydroxide in the effluent. Alkalinity is expressed in mg/L of equivalent calcium carbonate (mg/L $CaCO_3$).

In anaerobic treatment systems such as the UASB, **pH** is one of the most important parameters that affect the anaerobic process. For optimal treatment the UASB reactor pH should be maintained at around neutral and should not fall < 6.6. The H_2CO_3 alkalinity requirements to control the minimum reactor pH are dependent on the types of organic matter present in the effluent. Effluents can be categorized into two basic categories as follows:

(i) Effluents that do not generate their own internal buffer and hence depend entirely on external buffer source to maintain the minimum pH in the reactor

(ii) Effluents that generate their own internal buffer hence requirement for external buffer source is partially or totally eliminated.

Alkalinity monitoring is essential to ensure appropriate amounts of **buffer materials** (such as sodium bicarbonate and soda ash) are added to the UASB reactor to compensate for the alkalinity drop to prevent process upsets due to pH level in the reactor dropping below 6.6.

9.21 How to control the MBR

MBR is also a variant of the activated sludge process. In the MBR, the **suspended growth process** is combined with the **membrane filtration process** to improve the biodegradation process hence a better effluent quality is produced. Similar process control parameters discussed above are applicable to MBR systems. Nevertheless, the magnitude of the acceptable ranges may be different. For example, the MLSS in MBR systems may be in the order of 10,000 mg/L or more as compared to 3500 mg/L to 6000 mg/L in an EAAS.

9.22 From the perspective of the DOE officer/inspector

As a DOE officer/inspector you are aware that other biological treatment processes (BPs) other than an activated sludge process and its variants may have **different PM parameters** specific to their process. You need to pay special attention to this aspect when inspecting these processes, such a ponding system or an UASB or a MBR.

CHAPTER 10:

ANALYSIS OF INDUSTRIAL EFFLUENTS FOR PERFORMANCE MONITORING OF BIOLOGICAL TREATMENT PROCESSES





CHAPTER 10:

ANALYSIS OF INDUSTRIAL EFFLUENTS FOR PERFORMANCE MONITORING OF BIOLOGICAL TREATMENT PROCESSES

10.1 Typical measurements in BP performance monitoring

The measurements listed below are commonly being encountered in the operation of **biological treatment processes (BP)** for the treatment of **organic effluents**:

(i) pH, dissolved oxygen, mixed liquor suspended solids, mixed liquor volatile suspended solids, biochemical oxygen demand, chemical oxygen demand, oxygen uptake rate, sludge volume index, nutrients, flowrate and jar testing.

(ii) Calculated performance monitoring parameters for the operation of activated sludge operational parameters include: SV_{30}, SVI, OUR, SOUR, recycled sludge, sludge wastage

10.2 Protocols for measuring performance monitoring parameters

Performance monitoring(PM) does not require very accurate analytical procedure, hence the use of **portable in situ instruments** and **modified methods** which could yield results in a relatively short time are preferred. The methods commonly used in practice by the industry to measure the performance monitoring parameters, which are also taught in CePIETSI course are summarized in Table 10.1. For IETS performance monitoring purposes, in-situ measurement methods which can provide quick results are more preferred. The modified methods may include USEPA-approved/accepted methods or methods approved or accepted by EPAs in other developed countries. This information can be obtained from the instrument manufacturers.

A brief discussion of the procedure to analyze some of the parameters is discussed in the following paragraphs.

10.3 Mixed liquor suspended solids (MLSS)

Samples of mixed liquid from the **aeration tank** are filtered and heated for an hour in an oven at **105°C**. This are then weighed to compute the **total suspended solids** (TSS) present in the sample. The solids in the aeration tank liquid are referred to **mixed liquor suspended solids (MLSS).**

10.4 Mixed liquor volatile suspended solid (MLVSS)

The filters containing solids from the previous experiment are then placed in a muffle furnace at **600**°C where the organic materials burn off and the left over inorganic materials are weighed. The difference in weight from the previous experiment represents volatile suspended solids (VSS). The volatile suspended solids in the aeration tank are referred to as **mixed liquor volatile suspended solids (MLVSS).**

Table 10.1: Performance monitoring parameters and their test methods

Parameter/Test	Method
pH	SM 4500-H^+ B. Electrometric Method
ORP	SM 2580 B.
Dissolved oxygen	SM 4500-O G. Membrane Electrode Method
Mixed liquor suspended solids (MLSS)	SM 2540 D Total Suspended Solids
Mixed liquor volatile suspended solids (MLVSS)	SM 2540 E. Fixed and Volatile Solids
Sludge volume (SV30)	SM 2710 C

Sludge volume index (SVI)	SM 2710 D
Biochemical oxygen demand	HM 8043 EPA-Accepted, adapted from SM 5210 B
Chemical oxygen demand	HM 8000 40 CFR 136.3 approved; HM 8231 EPA accepted 410.3 or SM 5220 C, SM 5520 D
Oxygen uptake rate	SM 2710
Nitrogen	HM TNT 830, 813, 832 Equivalent EPA 350.1, SM 4500-NH_3 G or H; HM 8038 (Ammonia, as Nitrogen); SM 4500-NH3 C
Phosphorus (orthophosphate)	HM 8048 Accepted SM 4500-P E; HM TNT 843, 844,845 Equivalent SM 4500-P E;
Flowrate	Beaker and stop watch
Sludge blanket/depth	Sludge depth meter

Note: (i) HM stands for Hach Methods: SM for standard Methods

(ii) Any instruments using any methods approved or accepted by USEPA or other EPAs in developed countries may be used.

(iii) Mention of models of instruments does not constitute endorsement of the instruments by the DOE

10.5 Sludge volume (SV_{30}) and sludge volume index (SVI)

Sludge volume is measured by allowing 1 L of mixed liquor sample taken from the aeration tank of the IETS at EiMAS to **stand undisturbed** in a 1 L measuring cylinder and measuring the volume the sludge settles to after 30 minutes. This gives SV_{30}. A 100 mL of the mixed liquor is filtered and then left to dry overnight in an oven, at 105° C. **A straight SVI** is computed by using the following formula:

$$SVI = SV_{30}\ (mL/L)/\ 10 \times MLSS\ (g/L) \quad \text{..... (Equation 10.1)}$$

Sometimes when MLSS concentration is too high, a **diluted SVI** (DSVI) is recommended. DSVI is determined by **diluting** the mixed liquor (usually 1 in 2 (50:50), 1 in 4, or 1 in 8), and the sample is left to settle for 30 minutes. The dilution should be carried out using secondary effluent to ensure full compatibility of salinity values and chemicals. DSVI is computed using the following formula:

$$DSVI = SV_{30}\ (mL/L)/\ (1/2^{n}) \times MLSS(g/L), \quad \text{..... (Equation 10.2)}$$

where n is the dilution factor 1, 2, 3...

To simulate actual settling conditions in a secondary settler most accurately a **stirred SVI** (SSVI) is determined by allowing the sludge to settle for 30 minutes, usually in a 2L cylinder equipped with a stirring device that turns the sludge radially at a rate of 1 rpm. This gentle stirring action helps to overcome the hindered settling and compaction reactions. The calculation is about the same as for SVI, but values are much lower and simulate actual settling conditions in a secondary settler most accurately.

10.6 Biochemical oxygen demand (BOD_5)

The method consists of filling with sample, to overflowing, an airtight 300 mL BOD bottle and incubating it at 20 °C for 5 d. Dissolved oxygen is measured initially and after incubation, and the BOD is computed from the difference between initial and final DO.

BOD can be calculated by:

(i) Undiluted: Initial DO - Final DO = BOD
(ii) Diluted: ((Initial DO - Final DO)- BOD of Seed) x Dilution Factor

The method of BOD measurement used in this course is the **dilution method.** The DO levels in the sample should not be < 2.0 mg/L at the beginning and should be > 1.0 mg/L at the end of the test.

10.7 Chemical oxygen demand

The method involves pipetting a specific volume of effluent sample into a COD vial and **heating** it in a COD reactor at 105°C for two hours. After the vial has cooled down to room temperature, the COD of the sample is measured by using a s**pectrophotometer** with the appropriate wavelength selected. The COD value is reported in mg/L.

10.8 Specific oxygen uptake rate (SOUR)

Details of the test procedure are specified in the Standard Methods. The protocol involves measuring the DO level in a BOD bottle filled with a well mixed **aerated sample of activated sludge**. The DO level is recorded in one minute intervals for a period of 12 minutes. In order to have results that reflect true aeration basin conditions the SOUR should be performed without delay after the sample is taken. If the **initial DO** level in the sample is < 2.0mg/L manually aerate the sample. The **final DO** value in the sample at the end of the test should be above 1.0 mg/L, a number which is also used in BOD test rules. The gradient of the plot of DO (in mg/L) versus time (in minutes) gives the OUR in mg O_2/L. min. The activated sample must also be analyzed for VSS. Dividing the OUR by the VSS gives the SOUR in mg O_2/ min .g VSS which can be converted to mg O_2/ h .g VSS, the usual units for reporting SOUR.

10.9 pH measurement

In IETS operation, pH measurement of the effluent is performed at specific locations in the IETS by using a hand held pH meter or more commonly with a pH meter installed on site. pH meter calibration according to the manufacture's manual is an important aspect which needs to be paid attention to.

10.10 ORP measurement

Nowadays, the monitoring of ORP in the **biological reactors** by using an ORP meter is becoming an accepted practice. Calibration of ORP meter according to the manufacturer's manual must be strictly followed.

10.11 Flow measurement

Measurement of effluent flow rate in an IETS enables the IETS supervisor/operator to calculate **load** and perform **mass balance** analysis. Measurement could be performed with different methods like **magnetic flow meters** or **open channels** like Parshall flume or weirs, in which the flow is calculated as a function of liquid depth. Flow measurement is typically conducted at several locations in the IETS. A simple method of effluent flow measurement is by using the "pail and stopwatch method" which will give an **approximate** measure of the effluent flowrate.

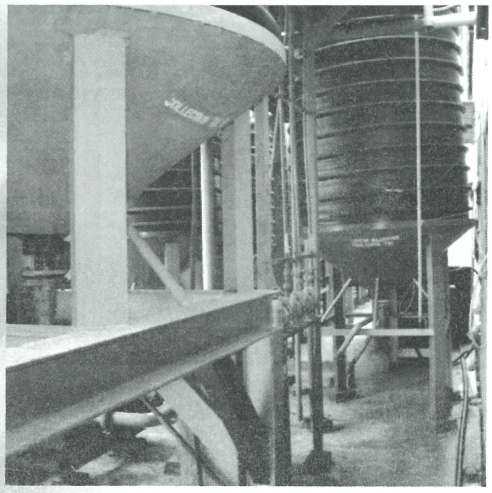
10.11 From the perspective of the DOE officer/inspector

As a DOE officer/inspector you understand that **effluent analysis** is an integral part of the implementation of PM procedure. The in situ effluent analysis and associated instruments used will provide the essential information from which important IETS **operational decisions** are made. You need to inspect that measurements are made correctly by following the established procedure and instruments maintained and calibrated according to the manufacturers' recommendations.

CHAPTER 11:

DATA ANALYSIS AND INTERPRETATION OF BP PERFORMANCE MONITORING DATA





CHAPTER 11:

DATA ANALYSIS AND INTERPRETATION OF BP PERFORMANCE MONITORING DATA

11.1 Data treatment

There are several ways of treating and analyzing the performance monitoring (PM) data of BPs obtained either from measurements conducted in the **laboratory**, **instrument readings**, or by using **portable instruments** or **on line instrumentation** system. Whatever the case is, there are certain common ways of handling the PM data that are appropriate for making useful interpretation for the purpose of IETS operation. The data handling techniques are discussed in the following paragraphs.

11.2 Data tabulation

The **Guidance Document on IETS Performance Monitoring (GD2)** issued by the Department of Environment prescribes the tables/log sheets to be used by field technicians to record their in-situ measurements and instrument readings of biological treatment processes (BP). These are shown in Appendix A, B and C to the GD2. The tables / logs can be modified to suit individual's situations.

11.3 Comparing the measured data with the recommended ranges

In biological treatment processes, the data obtained by the industry's IETS team from performance monitoring activities (in-situ measurements, instrument readings, laboratory measurements/analysis) are generally similar, irrespective of the actual biological treatment processes used. However, some processes may have more parameters; while some other processes may have less parameters to be monitored. The performance monitoring data of biological processes

include: **flowrate, BOD, COD, pH, ORP, MLSS, MLVSS, SVI, D.O., OUR, SOUR, nutrients, microscopic examination, and sludge depth** (for clarifiers). Oftentimes **bioassay testing** (such as whole effluent toxicity -**WET** testing) or **bioassay monitoring** (such as using treated effluent to rear native fish in ponds) is also conducted to monitor the impact of treated effluent on aquatic organisms. The task of an IETS supervisor in the monitoring of the operation of IETS-BP is more demanding than that of IETS-PCP because in BP, there are a lot more parameters to be monitored. Additionally, it is also a normal practice that the supervisor sets a more **conservative value** for each parameter to serve as a "**warning level**" to alert the IETS operators to initiate response actions when the "warning level" is reached. The **recommended ranges** for most of the performance monitoring parameters have been highlighted in Chapters 7, 9, 10 and throughout this Document. These **alarm levels** may physically be displayed as "**warning lights**" at conspicuous locations in the IETS, o "**flashing lights**" on computer screen or may trigger a message (email or sms) to be sent to the relevant IETS personnel.

11.4 Range control charts

Range control charts for the following parameters can be easily plotted by using a **statistical package** commonly available on a personal computer: **flowrate, pH, MLSS, MLVSS, SVI, D.O., OUR, and SOUR.** These are the relevant performance monitoring parameters for most biological processes (BPs).

Ponding systems which are categorized as **non engineered systems** and rely on **natural processes** for the biodegradation of the organics found in the effluents have only a few parameters to be monitored with even less frequency than the engineered systems. On the other hand, a UASB has a few additional parameters such as zone settling velocity (ZSV), volatile fatty acid (VFA), ORP and alkalinity. The relevant parameters for different biological treatment processes are summarized in Table 11.1. More details on performance requirements can be obtained by referring to GD2.

Table 11.1: Types of BP and the relevant parameters

Type of BP	Relevant PM parameters and associated PM activities
Ponding systems	Flowrate; pH; BOD; COD; DO; nutrients, sludge depth
TF	Flowrate; pH; BOD; COD, MLSS; MLVSS; DO; nutrients
RBC	Flowrate; pH; BOD; COD, MLSS; MLVSS; D.O.; nutrients;
CAS; EAAS	Flowrate; pH; BOD; COD, MLSS; MLVSS; SVI; F/M ratio; DO; OUR; SOUR; θ_c; ORP; nutrients; microscopic observation
UASB	Flowrate; pH; BOD; COD, MLSS; MLVSS; SVI; F/M ratio; ORP; OUR; SOUR; θ_c; VFA; ZSV; nutrients; microscopic observation
Final clarifier	Flowrate; SS; sludge depth (DOB)

11.5 Mainstreaming IETS agenda through IETS status report

The IETS team must make an effort to establish effective procedure to make their presence on the premise felt by their organization. This can be accomplished by setting up a **reporting mechanism** where **status reports** are prepared on a scheduled basis and sent to all relevant **key personnel** within the industry organization. It is recommended that a **summary report** is submitted to the **performance monitoring committee** (**PMC**) and management to summarize the findings/observations based on the data collected. Such a report which can be prepared on a **daily or shift basis** may look like the one illustrated in Fig. 11.1.

Extended Aeration Activated Sludge (EAAS)

Findings

Based on the performance monitoring conducted today (March 16, 2012) from 8 a.m. to 4..p.m and the data collected, the following conclusions can be made about the EAAS:

(a) The IETS was functioning in good working conditions with an overall BOD removal efficiency of …% and the discharge of final effluent complying with all the parameters stipulated in Standard B, IER.

(b) The performance monitoring parameters of MLSS, MLVSS, SVI, SOUR…… were all within the recommended ranges.

(c) The D.O. level of ….. in aeration tank was slightly below the recommended range

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

Recommendations

(a) The cause for the low D.O. in the aeration tank needs to be investigated and corrected immediately

(b) The N:P:BOD ratio which is out of range needs to be investigated and corrected. Analysis and computation of N:P:BOD ratio may need to be repeated.

Prepared by IETS supervisor/operator: …… ……..Checked by competent person……

Signature…….. Signature……..

Date & Time…… Date & Time……

Fig. 11.1: Example of Daily/Shift Report for a Biological Process

It is common practice for some industries to conduct **shift** or **morning meetings** where the status of operation of relevant sections/units in the industry is discussed. The subject matter discussed includes the **status of IETS performance**. This practice is highly recommended. A **one page daily /shift report** summarizing the IETS performance can be prepared. The report can take the form of **graphical plots** of all relevant performance monitoring parameters with definitive statements whether the parameters are within the acceptable ranges hence the IETS is performing in satisfactory fashion or otherwise. In the case where the parameters are not within the recommended ranges, the problem needs to be highlighted and effective corrective action identified and agreed on. Another recommended practice is to prepare a one to two page **Monthly Summary or Status Report** (typically in

the form of **graphical plots** too) of the PM data to be sent to the relevant factory personnel including the top management. An example of such a report is given in Fig. 11.3.

Establishment of effective communication line will create a **well informed management** that will be **sensitive** toward regulatory compliance hence will result in less chance of the industry be involved in unnecessary **enforcement actions**. **Corporate image** will not be tarnished and business growth affected by issues of environmental governance.

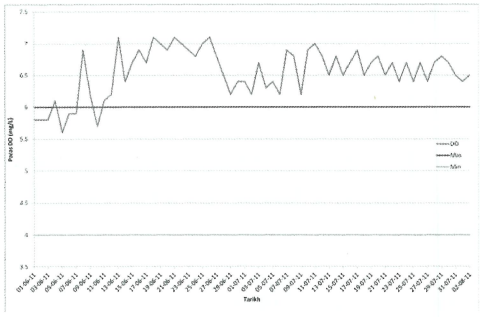


Fig. 1 : Graph of DO vs time

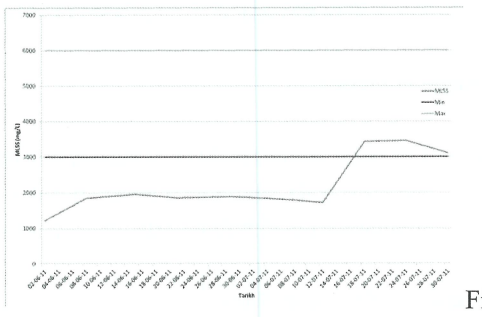


Fig. 2 : Graph of MLSS vs time

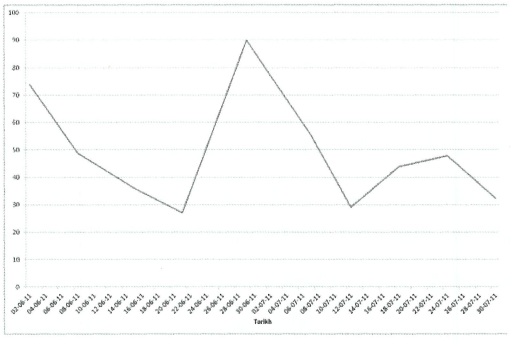


Fig. 3 : Graph of MLSS vs time

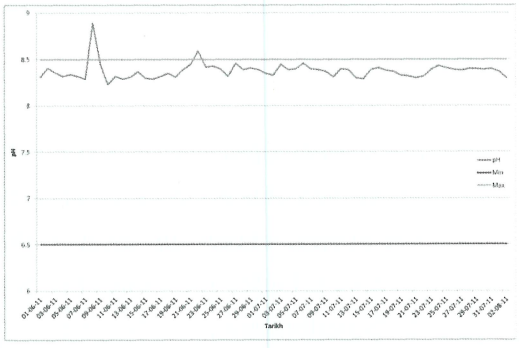


Fig. 4 : Graph of pH vs time



Fig. 5

: Graph of VFA/COD and efficiency vs time (UASB)

Conclusions

All PM parameters were within the acceptable ranges. The final effluent quality complied with the discharge standards for all parameters.

Competent person..... Signature..... Date.....

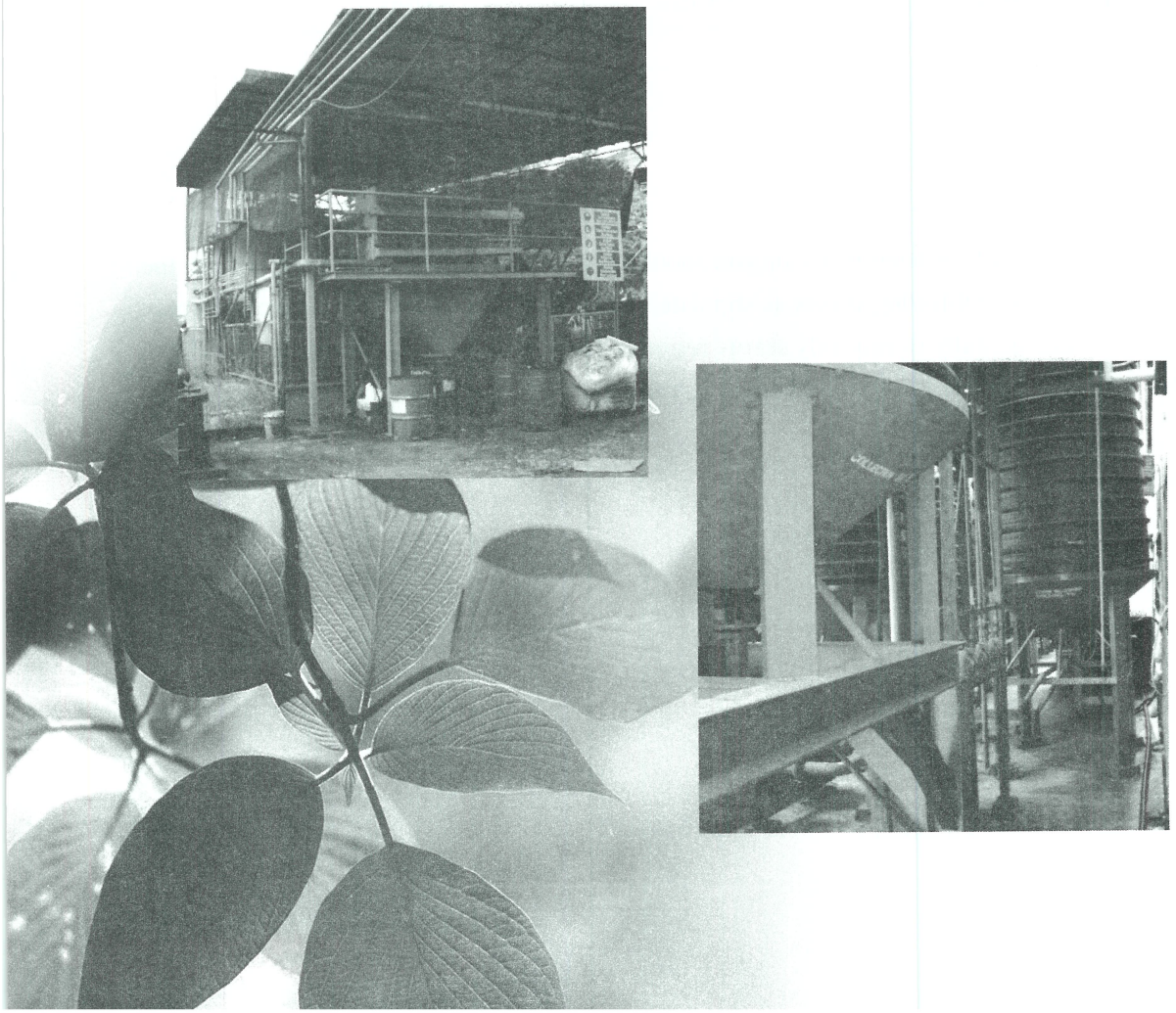
Fig. 11.2: Example of Monthly IETS Status Report for Biological Processes

11.6 From the perspective of the DOE officer/inspector

As a DOE officer/inspector you should ask for and inspect the PM records in the form of **tables/log sheets** as stipulated by GD2. Other records to be inspected may include **daily** or **monthly status reports.** The data will show whether the BPs have been operated in a sound manner according to the principles explained in chapter 9.

CHAPTER 12:

PHYSICAL CHEMICAL TREATMENT PROCESSES -THE WORKING CONCEPTS



CHAPTER 12:

PHYSICAL CHEMICAL TREATMENT PROCESSES -THE WORKING CONCEPTS

12.0 Success of IETS operation

The success of operation of an IETS is reflected in the quality of the **final effluent**. At the operational stage of an IETS, as a DOE inspector, your main objective is to ensure the maintenance of **optimal operating conditions** for effective operation of the IETS. Effective operation translates into better final effluent quality being maintained on a continuous basis. This is achieved by maintaining the process parameters within the **stipulated ranges.**

This chapter will equip the DOE officers with the required **working concepts** before going into the discussion on how to control and maintain the physical chemical treatment process. The working concepts presented in this module will not be explained from a purely theoretical standpoint but rather from **practical application** perspective. The following PCPs commonly employed for the treatment of industrial effluents will be discussed:

A. PRELIMINARY/PRETREATMENT

Equalization
Clarification and sedimentation
pH adjustment and neutralization
Coagulation and flocculation
Hydroxide precipitation
Sulfide precipitation
Carbonate precipitation
Other precipitation technologies
Gravity separation

Dissolved air flotation
Ion exchange
Oxidation reduction

B. TERTIARY/ADVANCED TREATMENT

Carbon adsorption
Chemical oxidation
Advanced oxidation processes
Media filtration
Membrane filtration
Evaporation

12.1 Equalization (EQ)

In most situations, an equalization unit is an integral component of an IETS whether the IETS is treating an organic or an inorganic effluent, Equalization is an important unit operation which has an impact on the subsequent treatment unit operations or processes.

Equalization of effluents is always required to **even out fluctuations** in:

- Flow
- Pollutant concentrations
- pH

Effluent with constant flow rate and little swing in pollutant concentrations will be more easily 'handled' by the subsequent treatment process, which may be a biological process, such as an activated sludge process or a physical chemical process, such as a metal precipitation process. Equalization units/tanks (EQs) are known by different names such as **holding tanks, equalization basins** or **equalization lagoons,** which may be designed as open above ground tanks or covered buried tanks. Sometimes, the EQs are provided with **mixers** or **aerators.**

12.1.2 From the perspective of the DOE officer/inspector

As a DOE officer/inspector you understand the important function of the EQ in your IETS. The mixers or aerators need to be maintained properly in order to produce a **homogenized** effluent from the EQ for the subsequent process.

12.2 pH Adjustment and neutralization

Acids and **alkalis** are used widely in industrial manufacturing processes. Acids are categorized as **organic** or **inorganic (mineral) acids**. Mineral acids **dissociate** completely while organic acids dissociate partially. Examples of mineral acids widely used in industrial applications are:

- Sulfuric acid (H_2SO_4) - used in manufacture of agricultural fertilizers, dye; and in iron and steel industry
- hydrochloric acid (HCl) - used for metals pickling, ion-exchange regeneration; as raw material for the production of numerous inorganic and organic compounds
- nitric acid (HNO_3) -used in manufacture of fertilizers, dyes, drugs, plastics, and explosives
- hydrofluoric acid or hydrogen fluoride (HF)-used for etching; in chemical, metallurgical, glass, solar cells, atomic energy, mining and petroleum exploration industries.
- Phosphoric acid (H_3PO_4) - used in manufacture of rust removers, beverages and tangy foods

Examples of organic acids used in manufacturing processes include:

- Acetic acid (CH_3COOH) -used in pharmaceuticals and textile industries
- Oxalic acid ($C_2H_2O_4$)-used for manufacture of household cleaning chemicals
- Formic (HCOOH) - used in pharmaceuticals and chemicals industries and pesticides manufacture
- Citric ($C_6H_8O_7$) - used in food, confectionary and beverage industries.

Industrial alkalis refer to **sodium hydroxide** (NaOH), **potassium hydroxide** (KOH) and **sodium bicarbonate** (Na_2CO_3). Sodium hydroxide finds wide applications in industries, such as pulp-and-paper mills, and for manufacture of glass, soap, miscellaneous chemicals, textiles, cleansers and detergents. In many industrial applications, potassium hydroxide can be used as an alternative to sodium hydroxide. Commonly, it is used in the manufacture of soaps, biodiesel, batteries, fuel cells and fertilizers.

12.2.1 Working concepts of pH adjustment

The use of the acids and alkalis leads to elevated pH levels in the effluents which then require pH adjustment. pH adjustment is a general term referring to the process of **adjusting** the pH of the effluent to any desired pH value while neutralization is the adjustment of pH to a pH of 7.0. pH adjustment is carried out for several reasons such as:

- To **prepare the effluent** for subsequent biological treatment process such as the activated sludge process. The microorganisms require a pH range of 6.5 to 8.5 for optimal growth and hence effective removal of organics.
- Many physical chemical treatment processes are **pH dependent** hence pH must be adjusted for the reactions to take place. This is true for coagulation and flocculation processes, oxidation-reduction processes and precipitation of metals.

Typical **neutralizing chemicals** used are:

Acid: Hydrochloric (HCl) or nitric acid (HNO_3)

Alkali: Sodium hydroxide (NaOH)

pH adjustment or neutralization reaction is an **exothermic** (heat generation) process. In typical industrial applications in Malaysia, pH control systems come either in the form of **batch mode** application or **continuous mode** application. If the pH of the effluent is desired to be adjusted to a **tight pH band, batch treatment** is preferable where the addition of neutralizing

chemicals is continued until the desired pH is achieved. On the other hand, if a **wider pH band** is required (such as in a metals precipitation process where pH needs to be controlled above 9.5), a **continuous pH control** system is employed. The **pH sensor and controller** is interlocked with the **chemical dosing system** which is actuated and delivers the neutralizing chemicals until the desired pH range is achieved.

The **difficulty** of achieving a narrow pH band set point is due to the **logarithmic relationship** of hydrogen ion concentration $[H^+]$ with pH as shown below:

$$pH = - \log_{10} [H^+] \quad \text{..... (Equation 12.1)}$$

12.2.2 Application of pH adjustment process

In IETS application pH adjustment is performed in several situations such as prior to a biological process, a coagulation or flocculation process, an ion exchange process or for precipitation of metals as metal hydroxides.

12.2.3 From the perspective of the DOE officer/inspector

pH adjustment is a common feature in most IETSs. This paragraph discusses the importance of maintaining pH within a certain range to ensure biological or physical chemical treatment processes occur in an optimal manner. As a DOE officer/inspector, you need to inspect or check on the following:

- The upkeep of the neutralizing chemical **dosing system**
- The maintenance of **stock** preparation and storage
- The maintenance of **pH sensors**

12.3 Clarification

Clarification or sedimentation is a common and essential process in industrial effluent treatment where suspended solids are made to settle from suspension resulting in the separation of solids from the aqueous phase. The clarified effluents will then be discharged or undergo other treatment processes to remove other contaminants.

12.3.1 Working concepts of clarification process

There are three kinds of settling as follows:

- Discrete settling
- Flocculent settling
- Hindered settling

The **three** types of settling are briefly described below.

Discrete settling (Type I):

- Settling of **dilute** concentration (<500 mg/L) of **discrete** suspended solids.
- Particles maintain individuality; no interaction; constant size, shape, density and particle settling velocity.
- Not relevant to settling of typical industrial effluents.
- Examples: settling of grit, fly ash; coal.

Flocculent settling (Type II):

- Settling of **dilute** concentration (<500 mg/L) of **flocculent** particles.
- Particles interact and agglomerate during settling; size; shape; density change.
- As floc increases in size, density decreases but velocity increases.
- Examples: settling of primary suspended solids of pulp and paper mill effluent or sewage in primary sedimentation tanks.

Hindered or zone settling (Type III):

- Settling of **moderate or high** concentration of suspended solids (>700 to 2000 mg/L or higher) that forms **flocculated** suspension/ lattice structure;
- Particles settle as a mass (blanket settling); distinct solid liquid interface develops.
- Examples: settling of suspended solid in secondary clarifiers of biological treatment processes and chemical flocs in physical-chemical treatment processes.

12.3.2 Application of clarification process

Sedimentation of **primary effluents** is carried out if the effluents contain a high concentration of suspended solids (e.g. pulp and paper mill effluents). Sedimentation is also required to remove **biological solids** in effluents from the **secondary treatment** processes (biological processes) e.g. activated sludge process) or **chemical solids** in effluents from physical chemical treatment processes (e.g. coagulation and flocculation process or metals precipitation process).

Several types of clarifiers/sedimentation tanks are used for the clarification process. They can be **rectangular, circular**, or in the form of **inclined plates** which increase separation area in small spaces. The clarifiers are commonly designed with some form of **solids removal mechanism** to collect and concentrate the settled suspended solids.

12.3.3 The Lamella clarifiers

One of the more common types of inclined plate clarifiers for the clarification of suspended solids from PCPs is the Lamella clarifiers. They consist of inclined plates which provide a large **effective settling area** within a considerable smaller footprint. The solids in the effluent settle

onto the inclined plates and accumulate in the **collection hoppers** at the bottom of the clarifier. The clarified effluent leaves the clarifier through the outlet weir. Compared to the conventional clarifiers, Lamella inclined plate clarifiers may require only 10% of the footprint of the conventional clarifiers.

12.3.4 From the perspective of the DOE officer/inspector

Clarification, sedimentation or settling is an important process in any IETS. As a DOE officer,inspector you need to make observation to ensure the process occurs in an effective manner (See section 12.4.10*)*. A successful clarification process will yield **clear effluent** free from suspended solids.

12.4 Colloids and the settling process

In this subchapter, a brief discussion of the interrelated concepts such as colloids properties, zeta potential, coagulation, and flocculation will be presented.

12.4.1 Colloids

A **colloid** is defined as a suspension of finely divided solids which have acquired an **electric charge** due to the absorption of ions on their surface. Typically, all of the solids of a given colloid take on the same charge and thus are repelled by one another. Most suspended solids found in industrial effluents carry a **negative charge**. As a consequence of the repelling force, they remain **dispersed** and **do not settle out**. Colloids are the most difficult suspended solids to remove because due to their **small size**, both sedimentation and filtration do not easily capture them.

12.4.2 Coagulation

In effluent treatment operations, the processes of coagulation and flocculation are employed to increase the effectiveness of the separation of suspended solids from the aqueous phase. These processes, usually done **in sequence**, are a **combination of physical and chemical processes.**

Coagulation is the **destabilization** of colloids by **neutralizing** the repulsive forces that keep them apart. This is accomplished by the addition of **chemical coagulants** which are typically **positively charged** that will neutralize the negative charge of the colloids. As a result, the particles collide to form larger particles (flocs) that will settle our more easily.
The **amount of coagulant** to be added to the effluent depends on the **zeta potential**, a measurement of the magnitude of **electrical charge** surrounding the colloidal particles. The bigger the magnitude of the repulsive force is the bigger will be the zeta potential; subsequently, more coagulants will be needed to neutralize the repelling force.

During coagulant addition, **rapid mixing** is required to disperse the coagulant throughout the entire liquid. Mixing energy is governed by the **velocity gradient** (G) which should be maintained within the range of 300 to 1000 s^{-1}, depending on the type of reactors. **Overdose** of coagulants should be avoided because it can cause a complete charge reversal and **restabilization** of the colloid complex.

Coagulation is usually described as a **charge neutralization** process by the use of coagulants. Some coagulants serve a dual purpose of both coagulation and flocculation in that they create large flocs that readily settle.

12.4.3 Examples of coagulants

There are two types of coagulant chemicals, the **primary coagulants** and the **coagulant aids**. Primary coagulants act as the **charge neutralizer** while coagulant aids help to produce stronger, quick forming, **dense** and **rapid-settling flocs.** These coagulant aids can also help reduce the amount of primary coagulant needed and the amount of sludge produced during the treatment process. Some examples of typical coagulants commonly used in industrial effluent treatment field are:

Hydrolyzing metal salts

- Aluminum sulfate (alum)
- Ferric chloride
- Ferric sulfate

Pre hydrolyzed metal salts

- Polyaluminum chloride (PAC)
- Polyaluminum hydroxychloride (Aluminum chlorohydrate)
- Polyaluminum chloride
- Polyferric chloride

Cationic polymers

- Polyquaternary ammonium chloride- epichlorhydrin-dimethylamine

Aluminum sulfate, ferric chloride and ferric sulfate are widely used coagulants for the treatment of industrial effluents. **Aluminum sulfate** ($Al_2(SO_4)_3$) or commonly known as alum is commercially available in solid or liquid form. In water it will be converted to **aluminum hydroxide** which exhibits an **emphoteric** behavior. The aluminum hydroxide floc is positively charged in acidic environment and negatively charged in alkaline environment. Since more positive aluminum ions are present in acidic range, **lower pH** favors more effective coagulation.

Alum is effective in attracting **inorganic suspended solids**, hence is widely used in PCP. Optimal application requires pH to be maintained within 5.5 to 7.5. Ferric chloride and ferric sulfate are used as **alternatives** to alum. The optimum pH range required is between 5.5 to 8.5.

PAC is effective over a wide pH range while optimum pH range for aluminum chlorohydrate is between 7.5 to 9.5.

Coagulant aids are typically **organic** or **inorganic materials** added to increase the **density** and **toughness** to the flocs so that they will not break up during the mixing and settling processes. Generally, coagulant aids are very **expensive,** hence are only used when necessary. Common coagulant aids include:

Inorganic coagulant aids

- Bentonite
- Kadinite
- Calcium carbonate
- Sodium silicate (activated silica)
- Aluminum chloride

Natural polymers

- Chitosan
- Starch
- Sodium alginate

Polyelectrolytes (synthetic polymers)

- Cationic polymer (e.g. polydiallydimethylammnonium chlodride)
- Anionic polymer (e.g. polyacrylic acid, polyacrylates, hydrolyzed polyacrylamides)
- Non ionic polymer (e.g. polyacrylamides, polyethylene oxides)

The **polyelctrolytes** are high molecular weight polymers which are largely **unaffected** by pH. They are the more widely used coagulant aids for effluent treatment applications. Typically applied in **low dosage** of 5 to 10 mg/L, they form bridges between the particles or charged flocs resulting in enhanced particles coagulation.

12.4.4 Zeta potential

Zeta Potential refers to the **electrostatic potential** generated by the accumulation of ions at the surface of the colloidal particle. The repulsive forces will prevent the particles from settling. To neutralize the charges/ reduce the zeta potential coagulants, such as **alum, ferric chloride** and/or **cationic polymers** are added to the effluents. Measurement and monitoring of zeta potential is a convenient way to **optimize coagulant dosage** in effluent treatment.

12.4.5 Flocculation

In the flocculation process, polymers which are **high molecular weight organic molecules** are added to the coagulated effluent to promote the **aggregation** of the suspended solids into particles large enough to settle by forming bridges between the flocs. Other benefit of flocculation is that it changes the physical nature of the floc, resulting in **less gelatinous sludge** which is easier to dewater.

In this process the flocculating agent must be added by **slow and gentle mixing** to allow for contact between the small flocs and to agglomerate them into larger particles. Additionally, the newly formed flocculated particles are quite fragile and can be broken apart by intense mixing. Mixing energy is dictated by the **velocity gradient** (G) which should be controlled within an acceptable range, typically 10 to 100 s^{-1}. depending on the type of flocs. As in the case of coagulation, flocculant **overdose** should also be avoided because it can lead to **settling/clarification problems**. Anionic polymers themselves are lighter than water, hence increasing the dosage will increase the bouncy of the floc and cause it to **float** and not settle.

Flocculation is usually described as the process of **agglomeration of the particles**.

12.4.6 Examples of flocculants

Flocculants or sometimes called flocculating agents are typically high, medium and low molecular weight **cationic** and **anionic polymers** which are commercially available either in **liquid** or **powder** forms. The chemical agent itself is known as the **flocculent** while the resulting floc is called the **flocculent**.

Some common flocculants include:

Mineral flocculants

- Sodium silicate (activated silica)
- Bentonite
- Certain metallic hydroxides with a polymeric structure (alum, ferric hydroxide)

Natural polymers

- Starch derivatives
- The polysaccharides
- The alginates (non ionic)
- Chitosan

Synthetic polymers

- Non ionic (polyacrylamide)
- Anionic polymer
- cationic polymer

The most common polymers used for industrial effluent treatment are those **synthetic polymers** based on **polyacrylamide**, which is a **nonionic polymer**. Their effect is the bridging between particles by polymer chains.

12.4.7 Factors influencing coagulation and flocculation

In industrial effluent applications, two most important parameters which influence the coagulation/ flocculation process are **pH, alkalinity** and

temperature. The optimum pH range varies depending on the coagulants used and is typically determined by **laboratory testing** commonly known as **jar test** experiments.

12.4.8 Jar test

A laboratory procedure commonly known as "jar test" is routinely conducted to determine the **optimum pH** and the **optimum dose** of coagulants and flocculants. The jar test simulates the coagulation and flocculation processes. In the first experiment, to determine the optimum pH, the pH of the raw effluent is adjusted (typically from pH 5 to 7.5) while the dose of the coagulant or flocculent is fixed (typically 5 to 10 mg/L). The result of the experiment is plotted as turbidity (or SS) vs pH. The optimum pH which gives the **best effluent quality** (lowest turbidity or suspended solids value) is read off from the graph. In the second experiment the pH of the raw effluent is fixed at the optimum pH obtained in the first experiment while the coagulant/flocculent dose is varied (typically from 5 to 20 mg/L). The result of the experiment is again graphically plotted as turbidity (or SS) versus coagulant/flocculent dose. The optimum dose which results in the best effluent quality is then read off from the graph.

12.4.9 Removal of particles

Once suspended particles are flocculated into larger particles, they can be removed from the aqueous phase by the usual techniques: sedimentation, media filtration, or flotation. Sedimentation works on **density difference** between the suspended matter and the liquid. Filtration is usually accomplished by using several **filter media** such as sand and anthracite. If filtering process is used, the addition of a flocculant **may not be required** since the particles formed by the coagulation reaction may be of sufficient size to allow removal.

Flotation processes also function due to **density differences**, but in this case the density of the solid or oil and grease is reduced by attaching **air bubbles** to the solid phase. The suspended solids or oil and grease float to the top of the water surface and are then skimmed off.

12.4.10 From the perspective of the DOEofficer/ inspector

In most situations in effluent treatment, whether biological processes or physical – chemical processes are employed, coagulation and flocculation processes are an integral part of the IETS processes. The DOE officer/ inspector needs to fully understand the importance of the coagulation and flocculation processes, hence make observation to ensure that they occur in an optimal manner. Attention to the following needs to be given:

- The required **dose** of the coagulant and flocculants
- The required **pH** of the effluent stream for coagulation and flocculation
- The maintenance of the **chemical dosing system** including the chemical stock preparation and storage
- The observation of **floc** formation
- The maintenance of the **mixing equipment** (mixers)

12.5 Metals solubility

Solubility refers to the ability of a substance to **dissolve** in solution. A substance that is soluble readily dissolves in solution and does not precipitate. A substance that is insoluble does not easily dissolve in solution and stays in its solid form. The objective of metals removal in effluent treatment is to produce conditions that would force the metals to become **insoluble** and hence come out of solution. In industrial effluent treatment applications, metals can be forced out of solution and precipitated in several forms as: **hydroxides, sulfides, carbonates, sulfates or chlorides**. By en large, the most common method of metals removal by precipitation process is to precipitate the metals as **metal hydroxides**.

12.5.1 Working concepts of solubility graphs

A solubility graph is graphical plots of the metal **concentration in solution versus the solution pH**. The shape of the graphical plots depends on the type of metals and metal compounds as well as on the pH of the solution. The solubility curves represent **theoretical situation** which may not be followed exactly in practice due to interaction with the presence of other contaminants in the effluent stream.

Some heavy metals are **amphoteric** where their solubility reaches a minimum at a specific pH. The point (i.e. the pH value) of **minimum solubility** is different for each metal.

As mentioned earlier, in industrial effluent treatment applications, metals are commonly precipitated either as a metal hydroxide or a sulfide (or sometimes sulfate), a carbonate or sometime a chloride. These are discussed briefly in the following sections: 12.6 to 12.8.

12.5.2 Application of metal solubility graphs

The information on solubility is applied in the treatment process to remove metals from industrial effluents such as those generated from metal furnishing industries. The graphs show the regions where metals would precipitate as metal hydroxides, commonly referred to as the **precipitation regions**.

12.5.3 From the perspective of the DOE officer/inspector

The solubility curve for the metal(s) in the effluent that one needs to remove must be understood. Then the next step is to identify at what pH the metal(s) can be precipitated as hydroxide(s) to comply with the **discharge standard(s).** As a DOE officer/inspector, when inspecting the

operation of the precipitation system, the attention is focused on whether the **required pH range** for hydroxide precipitation is maintained and on other associated tasks related to the maintenance of pH adjustment system as highlighted in paragraph 12.2.3.

12.6 Hydroxide precipitation

The most commonly used method to remove soluble metal ions from solution is to precipitate the ions as a **metal hydroxide**. The process is readily automated and controlled by a simple pH controller. By raising the pH value of a solution with a common alkaline agent such as **lime ($Ca(OH)_2$)** or **sodium hydroxide (NaOH)** the corresponding metallic hydroxide compounds become insoluble and precipitate from solution. Figure 12.1 is metal hydroxide solubility curve for metals commonly encountered in effluent treatment applications.

12.6.1 Working concepts of solubility graphs

The precipitation typically follows the **chemical reaction**:

$$M^{-n} + n\,OH^- = M(OH)_n \quad \text{..... (Equation 12.2)}$$

The advantages and disadvantages of hydroxide precipitation for metals removal are in the following paragraph.

12.6.2 Advantages and disadvantages of hydroxide precipitation

The advantages and disadvantages of hydroxide precipitation process for the removal of metals from industrial effluents are given below.

Advantages

- Well established, simple, **inexpensive** technology
- For certain metals, **compliant effluent** quality easily achievable

- Process easily **automated**
- Can also remove **inorganic pollutants** such as fluorides and soap

Disadvantages

- Lead, manganese and silver not adequately removed
- Some metals require **reduction step**-e.g: Cr(6+) to Cr(3+); Se(6+) to Se(4+) or **oxidation step** eg: As(3+) to As(5+); iron and manganese need oxidation step too
- Cyanide-metal complexes; **organo-metallic complex** inhibit hydroxide precipitation-needs destruction of complexes
- Generate large quantities of **sludge** which are difficult to dewater
- Little precipitation occurs at pH<6

12.6.3 Application of hydroxide precipitation process

Hydroxide precipitation process is the most **widely used technique** for removing metals and some non metals from effluent streams. Some typical scenarios commonly encountered in the application of precipitation process for the removal of metallic ions from industrial effluents are discussed below.

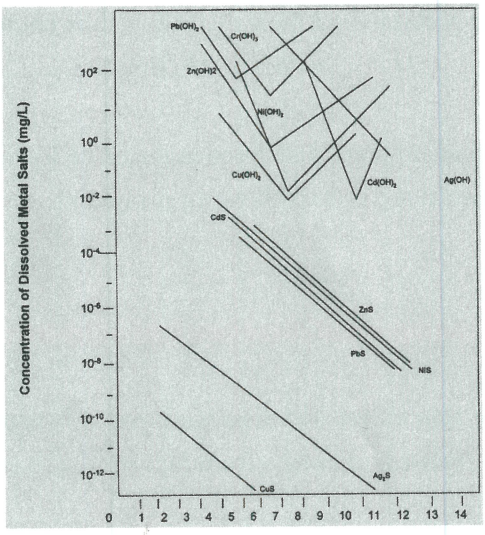


Fig. 12.1: Metals hydroxide and sulfide solubility (Source: EPA 625/8-80-003)

Removal of copper

pH of solution is normally raised to 9 to achieve effluent quality that complies with standard A (i.e.0.2 mg/L).

Removal of nickel

Nickel exhibits an almost similar curve as copper, but the curve is shifted at about 3 pH points higher. To achieve standard A (i.e. 0.2 mg/L) effluent quality, a pH value of 10 to 11 is required.

Removal of chromium

In industrial effluent scenarios, chromium exists as Cr^{6+} or Cr^{3+}. Hydroxide precipitation is applicable to the removal of Cr^{3+}. Typically, Cr^{6+} is firstly converted to Cr^{3+} which is subsequently precipitated as chromium (III) hydroxide. To comply with the discharge standard A for Cr^{3+} (i.e. 0.2 mg/L), a pH of about 8.0 is required.

The removal of Cr^{6+} involves **oxidation-reduction** reactions where Cr^{6+} is initially reduced to Cr^{3+} and followed with the precipitation of Cr^{3+} as chromium hydroxide. Typical reducing agents include ferric sulfate (Fe SO_4) sodium bisulfate (Na_2S_2O) or sulfur dioxide (SO_2). Reduction process is common and at low pH (pH < 3.0). Oxidation reduction reactions for industrial effluent treatment are discussed in section 12.12.

Removal of zinc

To achieve an effluent quality that meets the discharge standard B of 2.0 mg/L, the pH of the solution needs to be raised to 9.0 and above.

Removal of cadmium

To achieve an effluent quality of approximately 0.1 mg/L, the pH of the solution needs to be raised to 10.5. However, at this pH effluent quality may not meet the requirements of IER where the limit for standard B is 0.02 mg/L. To improve the effluent quality **coprecipitation** with ferric chloride (iron when hydroxide floc is formed) is normally practiced (see paragraph 12.6.4 on coprecipitation).

Removal lead

Lead can be removed by precipitation as lead hydroxide at pH 11.5 and above where effluent quality of 0.02 to 0.2 mg/L can be achieved.

Removal of arsenic

Arsenic is normally not presented in the pH solubility graph produced by the USEPA. In practice, arsenic is removed via coprecipitation with ferric chloride where effluent quality of 0.05 mg/L has been reported. Arsenic is present in several forms where As^{3+} is commonly found in industrial effluents. As^{3+} needs to be oxidized first to As^{5+} before the arsenic can be precipitated as Arsenic (V) hydroxide.

Removal of mercury

Generally, hydroxide precipitation is not effective over the wide pH range of 3 to 11. However, coprecipitation with ferric chloride has been reported to to produce very good effluent quality of less than 0.005 mg/L.

Removal of boron

Boron is also commonly removed as boron hydroxide in a pretreatment step. Subsequent treatment technologies include ion exchange, reverse osmosis, micro filtration and electro coagulation.

Removal of two or more metals

Let's take an example where both trivalent chromium and nickel are present in an effluent stream. To meet the regulatory discharge standards for both metals, a pH value that **precipitates both ions** must be chosen. If we were to comply with standard A (both metals: 0.2 mg/L), a pH value of approximately 10.0 and above will precipitate both metals.

When an effluent contains **multiple metals**, the general guide is to adjust the pH to a value of approximately 9 or above to precipitate all the metals..

12.6.4 Co-precipitation

As mentioned earlier, **metals theoretical solubility** may not exist in practice due to the presence of other chemical constituents in the effluent. Metallic coagulants such as **ferric chloride** or **aluminum sulfate** are generally added to the effluent to accelerate the coagulation and precipitation of the metals. Many chemical solutions such as the pickling bath used in **metal processing operations** may contain ferric chloride and aluminum sulfate and these will form co-precipitate with nickel and chromium as ferric hydroxide and aluminum hydroxide. As a consequence, a **lower concentration** of nickel and chromium in the effluent is achieved than the value predicted from the solubility graph, resulting in better effluent quality.

12.6.5 Complexing and chelating agents

Ammoniacal metal complexes

Several metal ions, particularly copper, zinc and cadmium easily form **metallic complexes** with ammonia. The ammoniacal metal complexes are very soluble in alkaline environment (high pH) prohibiting the precipitation of the metal hydroxides. Several methods are available for addressing the problem of ammoniacal complex hence the metal ion can be precipitated from the solution.

Destruction of metal ammoniacal complexes can be achieved by oxidation with **chlorine** or **ozone**. This method is comparatively more expensive than other methods. Another method of addressing the problem is by adding a soluble ferrous ion as either ferrous sulfate or ferrous chloride which will **co-precipitate** the metallic ion with the iron hydroxide. This has been discussed in section 12.6.4.

Another economical method is to precipitate the metals not as metal hydroxides but as **metal sulfides** by adding soluble sulfide ions. An example is the precipitation of copper as **copper sulfide** which is a very

insoluble compound. As the copper ion dissociates from the ammoniacal complex and forms the precipitate, ammonia is left behind in the solution. Sulfide precipitation is discussed further in paragraph 5.7.

Metal cyanide complexes

Cyanide formulations are used in many **electroplating solutions.** If cyanide is present in an effluent stream it will combine with several metals and form metal-cyanide complexes resulting in the unavailability of the metals for their removal as hydroxides. These metals include **iron, chromium** and **nickel.** The metal cyanide complex needs to be **destroyed** first before hydroxide precipitation can occur. This is achieved by **alkaline chlorination.**

EDTA metal chelates

Ethylenediamine tetraacetic acid (EDTA) is a polyprotic acid which is used in the food industry (as a sequestering food preservative) agent or in textile industry (as fiber treatment additives, dyeing and printing auxiliary). EDTA **chelates** or complexes metals inactivating them for further removal as hydroxide precipitation. Metal – EDTA chelates/complexes can be destroyed by **alkaline chlorination.**

12.6.6 From the perspective of the DOE officer/inspector

From the fundamental concept of metal hydroxide solubility, the DOE officer/inspector understands that it is not a difficult task to precipitate most metals and hence comply with the discharge standards. You should inspect the chemical precipitation system to ensure that the pH of the system is maintained within the required range for optimal precipitation. You also understand that the precipitation system is pH controlled, hence can easily be **automated** by using a **pH sensor** interlocked with the alkaline **chemical dosing system**. The entire system also needs to be inspected to ensure its proper functioning.

12.7 Sulfide precipitation

Sulfide precipitation is an alternative and attractive technology to precipitate metals from aqueous solutions.

12.7.1 Working concepts of sulfide precipitation

Metallic ions can also be precipitated from solution in the form of **metal sulfides**. Fig 5.1 also shows **solubility curves** for common metal sulfides. As can be seen, the sulfide solubility is several orders of magnitude **lower** than the comparable hydroxide. Hence **better effluent quality** can be achieved via sulfide precipitation.

Sulfide precipitation is typically accomplished with **inorganic sulfides** or less commonly with **sulfide rich organic compounds.** Examples of inorganic sulfides commonly used are sodium sulfide (Na_2S), sodium hydrogensulfide (NaHS), ferrous sulfide (FeS) and calcium sulfide (CaS). Organic sulfides are compounds in which a sulfur atom is covalently bonded to two organic groups.

12.7.2 Typical metals removed via sulfide precipitation

Sulfide precipitation is used to remove lead, copper, chromium (+6), silver, cadmium, zinc, mercury, nickel, arsenic, selenium, thallium, antimony, and vanadium from industrial effluents. Sulfide precipitation does not effectively treat the trivalent states of iron or chromium. Although the precipitation process can be accomplished at around neutral pH range, the process is always conducted under **alkaline conditions (pH: 7 to 9)** to promote sulfide ion formation. One advantage of sulfide precipitation is that it is rather **insensitive** to the presence of **chelating (complexing) agent.** Typical detention time in reaction tank is in the order of 30 minutes.

Sulfide precipitates tend to form colloidal particles requiring the addition of **coagulants** to settle. The precipitates are removed by coagulation, flocculation, clarification or filtration. Although another advantage of sulfide precipitation is that the sulfide sludges are **easier to dewater** than hydroxide sludges, the former are more susceptible to oxidation resulting in **resolubilization** of the metals as sulfates. An additional disadvantage is the **evolution of H_2S** if the pH is not carefully maintained in the alkaline environment.

Chemical reaction involved in sulfide precipitation where sodium sulfide is used can be illustrated as:

$$Na_2S + Ni^{2+} = NiS\ (s) + 2Na^{+} \quad \text{..... (Equation 12.3)}$$

12.7.3 Advantages and disadvantages of sulfide precipitation

The advantages and disadvantages of sulfide precipitation for metals removal are given below:

Advantages:

- **High degree of removal** even at low pH
- High reaction rates therefore **low detention time**
- Selective metal removal and **recovery** are possible
- Metal-sulfide sludges have **better dewaterability** than metal-hydroxide sludges
- Sulfide precipitation is **less influenced** by presence of complexing agents than hydroxide precipitation
- Metal sulfides occupy **less volumes** than metal hydroxides
- Metal sulfides are **less subject to leaching** than metal hydroxides

Disadvantages:

- Possibility of emission of toxic **hydrogen sulfide gas**
- Potential of presence of **residual sulfide** in effluent
- Soluble sulfide process may generate **odor**

- **Higher** capital and operating cost than hydroxide precipitation
- Process can be relatively **complex**

12.7.4 Application of sulfide precipitation process

Sulfide precipitation is an alternative technology for removing metals and is applicable where compliance with **more stringent discharge standards** is required.

12.7.5 From the perspective of DOE officer/inspector

As a DOE officer/inspector you understand that a very **good quality** effluent (that is, it contains low levels of metal concentration) can be accomplished via sulfide precipitation technology. You would need to inspect the precipitation system to ensure that the pH is maintained in the **alkaline range** to prevent the evolution of **toxic hydrogen cyanide gas.** You also realize that comparatively, the sulfide precipitation system is **more complex** than the hydroxide system but it can produce a better effluent quality.

12.8 Carbonate precipitation

Several metals form **insoluble carbonates** hence they can be precipitated from industrial effluents via carbonate precipitation. These include **lead, manganese, cadmium, and nickel**.

12.8.1 Working concepts of carbonate precipitation

Some industrial effluents already contain enough carbonates to allow precipitation to occur naturally. In other cases, **inorganic carbonates**

(e.g., Na_2CO_3) can be added to the effluent to force the reaction to occur. For example lead cadmium at pH range of 7.5 to 8.5, effluent quality comparable to hydroxide precipitation can be accomplished.

Carbonate precipitation takes place only if carbonate ions (CO_3^{-2}) are present. Free carbonate ions are present only in **high pH environment**. Typically a caustic is added to the effluent to raise the pH. As discussed in earlier section (hydroxide precipitation) high pH's also promote the precipitation of the metals as hydroxides. As a result, carbonate precipitation can be regarded as a **co-precipitation** process.

pH values above 10 are not recommended to avoid the formation of **metal hydroxyl complexes** that can increase the metal solubility and reduce the precipitation effectiveness. Carbonate precipitates can be **dewatered more easily** than the corresponding hydroxide precipitates.

Chemical reaction involved in carbonate precipitation using sodium carbonate can be illustrated as:

$$Na_2CO_3 + Pb^{2+} \longrightarrow PbCO_3(S) + 2Na^+ \quad \text{..... (Equation 12.4)}$$

12.8.2 Application of carbonate precipitation process

Certain metals which cannot be adequately removed via hydroxide precipitation such as **lead** and **manganese** are commonly removed via carbonate precipitation.

12.8.3 From the perspective of the DOE officer/inspector

From the discussion in this section, you would know that it is possible to remove metals from the industrial effluent via the carbonate precipitation technology. However, the technology is not commonly used in Malaysia.

12.9 Other precipitation technologies

There are several metals and non metals which cannot be precipitated satisfactorily via the hydroxide, sulfide or carbonate techniques. Some of the metals include: barium, silver and mercury and fluoride (a non metal).

12.9.1 Removal of barium

Barium is typically removed as **barium sulfate**, which is highly insoluble. Effluent quality of 0.5 mg/L residual barium has been reported using this technology.

12.9.2 Removal of silver

Silver is usually present in industrial effluents as **silver nitrate**. Whenever economical and feasible, silver **recovery** is practiced because of its high value. A treatment option for removing silver is to precipitate it as **silver chloride** by the addition of excess chloride ions. An effluent concentration of 2.0 mg/L is achievable.

12.9.3 Removal of mercury

Removal of mercury by precipitation methods such as hydroxide precipitation and sulfide precipitation have been discussed in earlier sections. Other method is by precipitation with **sodium borohydrite**. Several references report that very good effluent quality can be achieved by **organo metallic precipitation** technology with residual mercury concentration of 0.01 mg/L or less.

12.9.4 Removal of fluoride

Fluoride is a **non metal** which is commonly present in effluent streams from various industries such as manufacture of semi conductor panels; solar panel; plastics; ceramics; petroleum refining and refrigeration industries: Fluoride is typically removed by precipitating it as **calcium fluoride** by the addition of calcium hydroxide according to the following **chemical reaction**:

$$Ca(OH)_2 + 2HF = CaF_2 + 2H_2O \quad \text{..... (Equation 12.5)}$$

In some applications a combination of calcium hydroxide and calcium chloride is used as the precipitating agent. **Coagulant** and **flocculant** may also be used to improve the removal process. Enhanced removal of fluoride has been reported in the presence of **magnesium,** attributed to the **adsorption** onto magnesium hydroxide floc. Typical pH range used in the reaction tank is 7 to 8. The precipitation system is typically **automated** with a pH controller and fluoride sensor.

12.9.5 From the persective of the DOE officer/inspector

As a DOE officer/inspector you know that for a few metals there are **alternative precipatition technologies** available to remove the metals from the effluents. Compliant effluents have been reported by using these technologies.

12.10 Gravity separation (for oil removal)

Oil and grease are generated by a wide variety of industrial premises such automobile parts manufacturing, steel fabrication, vehicles cleaning system, slaughter houses, meat and related industry, fish industry, dairy industry, oil refineries, petrochemical works, steel mills and vegetable oil refineries.

Oil and grease may originate from plant origins which are composed of triglycerides (collectively known as fats, oil and grease-**FOG**) or from byproducts of petroleum distillation to produce gasoline (known as **mineral oil**). Based on **oil droplet sizes**, different categories of oil are present in industrial effluents.

- **Free oil**: oil droplets 150 microns in diameter or larger
- **Dispersed oil**: oil droplet from 20 to 50 microns in diameter
- **Mechanically emulsified oil**: oil droplets less than 20 microns in diameter
- **Chemically emulsified oil**: oil droplets less than 20 microns in diameter with a chemical bond to other molecules
- **Stable emulsion/dissolved oil**: oil in solution with its carrier (i.e. machine cooling solutions)

12.10.1 Emulsifying agents

Detergents, soaps, surfactants and emulsifying agents are **surface active agents** which inhibit the occurrence of coalescence of the oil droplets resulting in the formation of **emulsions**. Free oil can be relatively easily removed but removal of dispersed and emulsified oil is more difficult.

12.10.2 Deemulsification techniques

Deemulsification (emulsion – breaking) of oil can be accomplished by a combination of **physical and chemical processes**. The most common approach to removing emulsified oils from industrial effluents is preceded by emulsion breaking step via one of the following methods:

(i) **Lowering the pH** of the effluent with an acid to break the weak oil – water bonds

(ii) **Using demulsifying agents** such as inorganic salts: alum, ferrous sulfate, ferric sulfate, ferric chloride, sodium hydroxide, sulfuric acid, lime or polymers (polyelectrolytes)

(iii) **Heating, centrifugation**, or **filtration**.

.**Laboratory testing** is usually performed to determine the effectiveness of the selected chemical in breaking the emulsions. The demulsified oil is subsequently separated from the water phase via coalescence or flotation techniques with the addition of coagulants and polymers.

12.10.3 Working concepts of gravity separation for oil removal

Gravity separators work on physical separation principles governed by **Stoke's Law** which describes the relationship between the terminal settling or rise velocity of a particle in a fluid under the force of gravity. Improved performance of gravity separators has been reported by introducing coalescing plates in the separator. The coalescing design is known by many different names such as parallel plate, corrugated plate, slant rib and tilted plate separators.

12.10.4 Application of gravity separation for oil removal

Oil and grease (O&G) is present in most effluents, hence O&G removal unit operation is a common feature in most IETSs. Conventional gravity separators such as American Petroleum Institute (**API**) separators, Corrugated Plate Interceptors (**CPIs**)/**TPIs** (tilted plate interceptor) separators are designed to remove only **free oil** (oil droplets 150 microns in diameter or larger). Table 12.1 summarizes the capability of API and CPI in removing oil and grease.

Table 12.1: O&G removal capability of API and CPI

Type	Achievable effluent quality, O&G
API	100 mg/L with droplet size of 150 micron
CPI	≤ 10 mg/L with an oil droplet 20 to 30 micron

Where emulsified oil is present, deemulsification needs to be carried out by the use of one of the techniques discussed in 12.10.2 prior to removing the oil by gravity separators or flotation techniques; the latter is discussed in section 12.11.

12.10.5 From the perspective of DOE officer/inspector

As a DOE officer/inspector, you understand that oil and grease (O&G) must be removed effectively to ensure the **downstream treatment processes** are not adversely affected by the presence of O&G. These processes could be a metals removal process (e.g. a hydroxide precipitation or an ion exchange technique) or a biological treatment process (e.g. an activated sludge or UASB). You need to inspect to ensure the pretreatment stage (deemulsification process) operates optimally by maintaining the required pH and chemical dose, as well as the actual oil removal unit (API or CPI) by performing scheduled maintenance. If a DAF is used, it also needs to be maintained in an efficient manner discussed in the next section.

12.11 Dissolved air flotation (DAF)

In the field of industrial effluent treatment, DAF systems are commonly employed to remove **suspended solids (SS), fats,** and **oils and greases (O&G)** from effluent streams. If the effluent contains a substantial amount of **particulate BOD** this may also be removed by the DAF system.

Industrial applications of DAF systems include the treatment of industrial effluents from following activities/sources:

- Petrochemical industries
- Aquaculture industry
- Food processing and packing
- Meat and poultry processing and packing
- Pulp and paper mills
- Dairy products
- Automotive manufacture
- Metal finishing
- Oil drilling and produced water
- Tanker deballasting
- Laundry operations
- Landfill leachate
- Effluent from a biological treatment process
- Paints
- Power plant

DAF systems are considered as **high-rate processes** when compared with more traditional gravity-based settlement systems hence, a **smaller foot print** is required. Additionally, DAF systems may offer a greater degree of **operational flexibility**.

12.11.1 Working concepts of DAF systems

DAF operating principle is purely a **physical process** where the influent may be **pretreated** by the addition of **coagulants** and/**or flocculants** or **pH adjusted** to ensure optimum conditions for coagulation and flocculation.

DAF systems come in several designs. In small DAF systems the **entire influent stream** is pressurized, whereas in large systems, a **portion of the treated effluent** is recycled, pressurized and mixed with the unpressurized incoming influent stream just prior to entering the flotation tank. When the pressurized effluent stream enters the flotation tank, the pressure is released back to atmospheric pressure resulting in the generation of **small bubbles**

as the dissolved air comes out of solution. These bubbles will increase the buoyancy of the suspended solids, oil and grease or chemical flocs entering the vessel and as a result they float to the surface of the flotation tank. A **mechanical skimmer** then pushes the floats to the **collection trough**. Sometimes, to prevent the gradual accumulation of **sludge build-up** on the flotation tank floor, a **floor scraper** may be provided.

The main components of a DAF system are:

- Flotation tank
- Compressor/pressurizing pump
- Air injection facility
- Retention tank
- Back pressure regulating valve

Figure 12.2 illustrates a schematic diagram of a DAF system incorporating a recycle flow.

DAF **performance monitoring** and process control parameters may include:

- Influent flow rate (Q)
- SS or O&G concentration
- Recycle pressure (P)
- Air flow
- Chemical dosage
- Recycle flow and recycle ratio (R)
- Skimmer speed
- Air to solids ratio (A/S)
- Hydraulic loading rate (HLR)
- Solids loading rate (SLR)
- Retention time

Compared to APIs and CPIs, DAFs offer greater **flexibility** for removing oil and grease or suspended solids from industrial effluents. Typically, A/S ratio is adjusted to respond to **changes** in SS or O&G concentrations.

12.11.2 From the perspective of the DOE officer/inspector

As a DOE officer/inspector, for performance monitoring purposes, you understand that the most important parameter to monitor is the **A/S ratio**, which is typically maintained in the rage of 0.03 to 0.05 mg air per mg SS **or O&G** Other tasks include inspecting the chemical **dose** required and efficient working of the chemical **dosing system** and the **skimmer**.

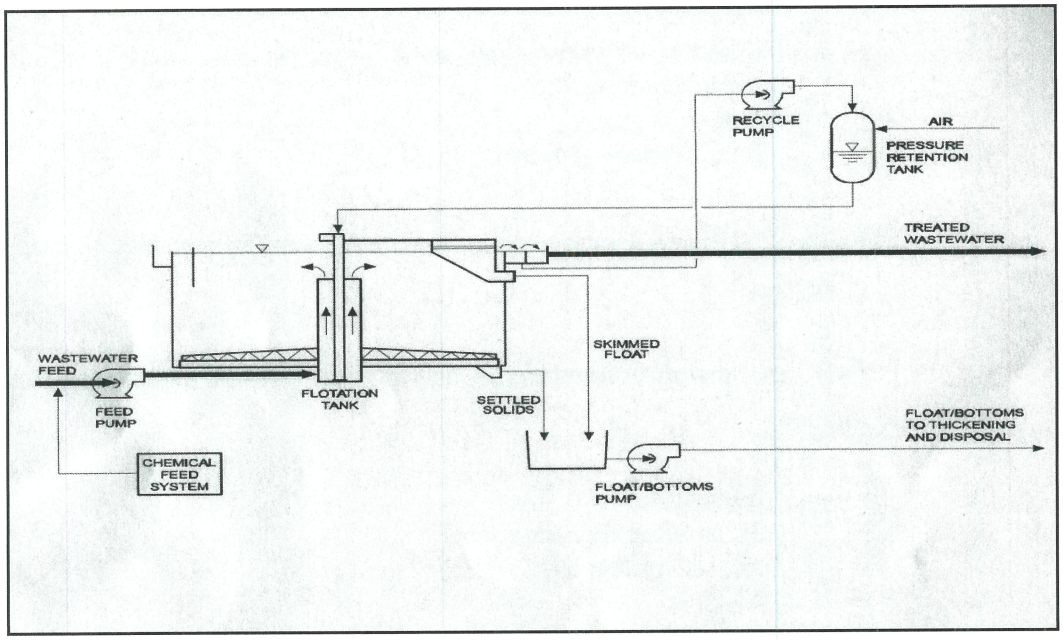


Fig. 12.2: Schematic diagram of a dissolved air flotation system-DAF (Source: Department of Defense, USA, 2004)

12.12 Oxidation and reduction

Oxidation-reduction reactions play a special role in the treatment of industrial effluents containing certain contaminants.

12.12.1 Working concepts of oxidation reduction process

An oxidation reduction (or redox) reaction is a reaction involving **electron transfer.** The substance that gains electrons is the oxidizing agent, while the substance that gives up electrons is the reducing agent. Some common applications of redox reaction in industrial effluent treatment include the **treatment of cyanide** via the **alkaline chlorination** process and the **treatment of chromium** (vi) via the **precipitation process.** These applications are discussed below.

12.12.2 Application of oxidation reduction process for chromium reduction

Chromium is one of the most common plating metals. Effluents containing hexavalent chromium are generated from chromium electroplating, chromate conversion coating, etching with chromic acid, and metal finishing on chromium metal. Hexavalent chromium (i.e., Cr^{6+}) is the soluble ion most commonly used in the plating bath and is much more toxic than the trivalent form (i.e., Cr^{3+}). Hexavalent chromium, which includes chromic acid (H_2CrO_4), chromium trioxide (CrO_3) and chromates, must be reduced to the trivalent state to allow for chemical precipitation as hydroxide. Some industries use a trivalent form of chromium, such as chromium trichloride ($CrCl_3$) or chromium sulfate [$Cr_2(SO_4)_3$], in the plating baths. Once the chromium has been reduced to its trivalent state, it can be chemically precipitated out of solution as chromium hydroxide [$Cr(OH)_3$].

Reduction of chromium (VI) to chromium (III) is typically accomplished by using gaseous **sulfur dioxide** or **sodium metabisulfite** as the **reducing agent** where the **ORP** is maintained at around 250 mV to 350 mV. (Note: reducing agents will reduce the ORP value of solutions). The reaction proceeds much faster at **low pH**, hence the reduction is normally carried out at a pH of 2 to 3 by the addition of **sulfuric acid**. Maintaining the pH around this range will also reduce the release of sulfur dioxide.

12.12.3 Application of oxidation reduction process for cyanide removal

Cyanide is also used in electroplating chemical baths as well as in gold extraction industry. Principally, these are two different methods for removing cyanide from aqueous solution, namely the **acid hydrolysis** method and the **alkaline chlorination** method. In the acid hydrolysis method, the pH of the solution is lowered with sulfuric acid (H_2SO_4) where **hydrogen cyanide** gas is generated. The gas is captured and subsequently recovered. Due to the evolution of hydrogen cyanide gas, the hydrolysis method is not popular for cyanide removal.

The alkaline chlorination method which is more commonly used for cyanide removal, involves a **two stage process.** In the first stage, the pH of the aqueous solution is raised to about 10 – 11.5 where **sodium hypochorite** (NaOCl) is used as the **oxidizing agent** to oxidize cyanide (CN) to cyanate (CNO). The ORP is maintained at a level of about + 325 mV to + 400mV. (Note: oxidizing agents will increase the ORP value of solutions).

In the second stage the cyanate is further oxidized to **carbon dioxide** (CO_2) and **nitrogen gas** (N_2) by adding additional chlorine. In the second stage pH is maintained at approximately 8.0 to 9.0 and ORP in the range of + 600 mV to + 800 mV.

12.12.4 From the perspective of the DOE officer/inspector

As a DOE officer/inspector you understand that the oxidation reduction processes are **controlled by pH and ORP** hence they need to be monitored closely and the required ranges for them maintained. Maintaining the pH and ORP for the chrome reduction will ensure Cr^{6+} is completely reduced to Cr^{3+} to enable the latter to be precipitated out of solution as chromium (III) hydroxide in the second stage. Maintaining pH and ORP in both stages in the alkaline chlorine process ensures that the cyanide is completely oxidized to carbon dioxide and nitrogen. In both cases, achieving **compliant effluents** will not be a challenging task to the IETS supervisor.

12.13 Ion exchange

In industrial effluent treatment scenarios, ion exchange process is commonly employed for the removal of metals (present as **cations**) from effluent streams. The process can also used to remove anionic species such as **cyanide, nitrates**, etc. from industrial effluents.

12.13.1 Basic concepts of ion exchange reactions

In industrial applications synthetic ion exchange resins are industrially manufactured as **porous beads** with diameters ranging from 0.3 to 1.3 mm. The most commonly used base materials for the resins are **polystyrene** and **polyacrylate.** Onto each of the **monomer units** of the polymer a **functional group** is attached. These functional groups will interact with ionic species, either cations or anions in the effluent streams resulting in an exchange reaction. The ionic species will take the place of the functional group on the polymer while the functional group goes in solution. The exchange reaction is a **reversible reaction** which is made use of in the regeneration step of the operation cycle of an ion exchange column. In the

regeneration process, the ion exchange columns are typically regenerated by passing **acids** (excess of H^+ ions), **salt-brines** (excess of sodium or chloride ions) or **alkali** (excess of OH^- ions).

Common **functional groups** are:

Positively charged: quarternary amine
Negatively charge: sulfonic, phosphonic, carboxyclic acid group

When all the exchange sites have been utilized, the column breakthrough condition has been reached hence the column needs to be **replaced or regenerated.** The regeneration process yields a **highly concentrated regenerant effluent stream** containing the removed metal which needs a special treatment or the metal can be recovered by the "**electrowining process**".

12.13.2 Application of ion exchange technique

Ion exchange technology is an alternative method that can be used to remove metals from effluents generated by a wide range of industries including printed circuit board manufacturing, semiconductor manufacturing, metal finishing, electroplating works, automotive and aircraft industries. When operated in an optimal fashion, **compliant** effluent can be achieved on a continuous basis. In certain situations, **metals recovery** may also be possible.

12.13.3 From the perspective of the DOE officer/inspector

From the discussion in this subchapter, as a DOE officer/inspector, you would need to enquire about the onset of the **breakthrough time** when the exhausted ion exchange column needs to be **replaced** or **regenerated.** In multiple column operation, the regeneration involving high effluent

flowrates process maybe **fully automated**.

Breakthrough time monitoring is achieved by monitoring the following:

- **Time of column usage**
- **Volume of through put** (effluent flow) through the column
- **Concentration of metal** in the column effluent

12.14 Activated carbon adsorption

Adsorption using activated carbon is a common technology widely used throughout the world for removing **residual dissolved organics,** typically from treated effluents from the biological process.

12.14.1 Basic concepts of carbon adsorption

Activated carbon has an extremely high **surface area** and possesses a **high affinity for organics**. The effluent is passed through a bed of granular/ powdered activated carbon until the **adsorptive capacity** of the carbon is exhausted (breakthrough time) or the treated effluent quality reaches the required design standard. At this time, the carbon in the carbon column is replaced with **fresh carbon** and the spent carbon is **disposed off** as **scheduled waste**. The column can also be regenerated either **on site** or **off site** at the vendor's premise.

12.14.2 Application of activated carbon adsorption

The presence of non biodegraded dissolved organics in treated effluents from the biological treatment processes is reflected in elevated **residual COD** levels. To achieve **compliant** effluent quality, the COD can be removed by passing the treated effluent through carbon adsorption columns. Carbon adsorption columns are a common feature in many industries in developed countries and are gaining popularity in Malaysia too.

12.14.3 From the perspective of the DOE officer/ inspector

As DOE officer/inspector you understand that adsorption columns have a defined useful life time hence when inspecting the columns you would need to be aware of how long the column has been in operation to ensure the **breakthrough time** has not been reached. The aspect of column regeneration or carbon replacement should also be enquired. Just like the case of ion exchange columns, this monitoring of the breakthrough time is typically done by several methods such as: volume **throughput** or **usage time or effluent quality.**

12.15 Chemical oxidation

Chemical oxidation can be utilized to oxidize contaminants in industrial effluents to produce.

- Terminal end products
- More biodegradable intermediate products
- More adsorbable product

Chemical oxidation offers flexibility in the choice of oxidants, combination of methods and environmental conditions. The most commonly used **chemical oxidants** are **chlorine** (Cl_2) and **ozone** (O_3). The application of chemical oxidation process for the treatment of industrial effluents is discussed below.

12.15.1 Chlorination

Chlorination of industrial effluents is sometimes practiced to remove **inorganic pollutants** (e.g. cyanide) or **organic pollutants** (e.g. various substances such as dyes). The use of chlorine for the removal of cyanide has been discussed in paragraph section 12.12.2. Chlorination of industrial effluents containing organic substances usually produces **chlorinated**

hydrocarbons which are objectionable from health standpoint. The use of chlorination technique for the removal of organics from industrial effluents is not common in Malaysia.

12.16 Advanced oxidation processes

Advanced oxidation processes (AOP) is an emerging technology which utilizes the strong oxidizing power of **hydroxyl radicals** to oxidize recalcitrant organics and color found in industrial effluents. Advanced oxidation is a form of **chemical oxidation** of the organics by the hydroxyl radicals which are highly reactive and short lived oxidants. There are several ways of generating hydroxyl radicals, including:

- Ultraviolet radiation/hydrogen peroxide
- Ozone/hydrogen peroxide
- Ultraviolet radiation/ozone
- Ultraviolet radiation/titanium dioxide
- Fenton's reagent

This subchapter focuses on the use of **Fenton's process** whose application in Malaysia has been reported.

12.16.1 Basic concept of Fenton's process

The Fenton's process uses the reagents: hydrogen peroxide (oxidant) and ferrous ions (catalyst). The general **chemistry** of Fenton's reagent is illustrated below:

$$Fe^{2+} + H_2O_2 \longrightarrow Fe^{3+} + OH^- + OH^* \quad \text{..... (Equation 12.6)}$$

12.16.2 Application of Fenton's process

The Fenton's process can be utilized to remove:

- Surfactants
- Solvents
- Color
- Odor
- Chelating agents
- Specific organic pollutants
- Chemical oxygen demand
- Petroleum hydrocarbons (BTEX, PAH, TpH, diesel)
- Phenolics, formaldehyde
- Pesticides
- Wood preservatives
- Leachate

The factors effecting the Fenton's process are namely H_2O_2 concentration. Fe^{2+}/H_2O_2 ratio, pH and reaction time. Other factors include the initial pollutant concentration and temperature.

Fenton's reagent can also be used for sludge treatment.

12.16.3 From the perspective of the DOE officer/inspector

The Fenton's process has its **maximum catalytic effect** at pH~3, hence as the inspector, you need to check if the **pH** of the system is maintained at this value. You would also need to maintain an **anaerobic condition** to prevent the formation of iron hydroxide that would reduce the catalytic effect of the Fenton's process.

12.17 Media filtration

Filtration is principally described as a mechanical solids-liquid separation process but other processes such as adsorption, straining and sedimentation also occur simultaneously. Filtration removes suspended solids but not dissolved solids.

There are different types of design of **media filters** which can be categorized based on **mode of operation** (continuous or intermittent), **type of bed** (stratified or unstratified), **filter media** (sand, garnet or anthracite), **filter bed depth**, **flowrate** (constant or variable) and **feeding method** (by pumping or gravity). Recent designs of continuous upflow sand filtration incorporate **internal washing system** which eliminates the need for backwash water storage tanks, backwash pumps and collecting tanks.

12.17.1 Basic concept of media filtration

The operation of media filters can be described as follows. The effluent enters the filter from the top and travels through the filter media and support graved. The filtered effluent is then collected through the **underdrain system**. As filtration proceeds, the **headloss** through the filter increases until it reaches a **predesigned level** or until a predetermined **effluent quality** (normally set in terms of suspended solid concentration) is reached. The filter is backwashed whenever the preset pressure loss level or the suspended solids breakthrough is reached. Generally, gravity filters are operated at 0.06 to 0.1 $m^3/min.m^2$ while pressure filters are operated up to 0.24 $m^3/min.m^2$. The filter media size ranges from 0.3 to 0.8 mm. Filters can be designed to have their suspended solids concentration and pressure loss reach their preset levels at the same time.

12.17.2 Application of media filtration

Media filtration is sometimes used to **polish** the treated effluents to further remove **fine suspended solids** to comply with stringent discharge standards.

5.17.3 From the perspective of the DOE officer/ inspector

As a DOE officer/inspector, you understand that as solids accumulate on the filter, the **differential pressure** will build up and when it reaches a preset value **backwashing** process will start to kick off. **Backwash water** needs to be returned to the IETS for retreatment. These aspects need to be looked at during inspection.

12.18 Membrane filtration

The membranes are **semi-permeable synthetic materials** which act as thin barrier sheets. The membrane technology, generally considered as an **advanced treatment technology** is used to treat treated effluents further to produce good quality effluents with low suspended solids concentrations or to remove small organic molecules or ions.

12.18.1 Basic concept of membrane filtration

There are two basic categories of membrane separation processes, **pressure driven** and **electrically driven**. In pressure-driven processes, hydraulic pressure is used to force the effluent through the membranes while the solids are retained in the influent and become the reject water or concentrate stream. The effluent that passes through the membrane is known as the **permeate**.

Depending on the size of the membrane pores, the pressure driven technologies are categorized as follows:

- **Microfiltration** (MF); pore size: <10 microns
- **Ultrafiltration** (UF); pore size: < 1 microns
- **Nanofiltration** (NF); pore size: < 0.1 microns
- **Reverse osmosis** (RO); pore size: < 0.01 microns

Typical operating pressures for the various types of filtration are given in Table 12.2 below.

Table 12.2: Type of filtration and the operating pressure

Type of filtration	Operating pressure (bar)
Conventional sand filtration	0.1 to 2
MF	0.2 to 2
UF	1 to 5
NF	5 to 20
RO	20 to 80

(Note: 1 bar = 10^5 N/m^2)

There is a fundamentally different membrane filtration process called electrodyalysis (ED) where ions are transported through the membrane under the influence of **electric potential**.

A common problem in the operation of membrane systems is **membrane fouling** caused by excessive presence of suspended solids and organic contaminants.

12.18.2 Application of membrane filtration

Where membrane filtration technology is used in industrial effluent treatment, its application is largely for the purpose of separating **suspended solids** from the effluents to comply with stringent internal discharge quality standards. However, industrial application for this purpose in Malaysia is rather limited.

5.18.3 From the perspective of the DOEofficer/ inspector

As a DOE officer/inspector, you understand that the influent to the membrane filter must contain low concentration of **suspended solids** to prevent membrane fouling. Some of the following operational parameters need to be monitored: flow, temperature, flux, recovery, trans-membrane pressure and specific ultrafiltration resistance (SUR) for UF filters to monitor the filter's performance.

12.19 Evaporation

In industrial effluent treatment, evaporation is an **alternative process** which can be used for several purposes, such as:

- concentrating or **removing heavy metals**
- concentrating or **removing hazardous materials**
- concentrating effluent streams prior to **additional treatment**
- producing water that is fit for **recycling**

The evaporation process may be accomplished naturally in **solar evaporation ponds**, or through the use of **mechanical evaporation equipment** which comes in various designs with different technical features related to the arrangement of the **heat transfer** surface and the method of imparting heat to the effluent to be treated.

12.19.1 Basic concept of evaporation techniques

In a typical evaporator, **condensing steam** on a metallic surface is used to provide the heat required to **vaporize the water** and as a consequence, a **concentrated solute** is obtained. The resulting vapor may be vented to the atmosphere, or condensed for reuse.

Another version of the evaporation technique which has gained wide application in effluent treatment field is **vacuum distillation**. In vacuum distillation, water reaches its boiling point at a much lower temperature than 100^{0}C (typically <38^{0}C). Not only water can be separated from the effluent using this technique, a broad range of **reusable components** in the effluent stream can also be **recovered**. Vacuum distillation is known by different names such as vacuum evaporation or cold vaporization.

12.19.2 Application of evaporation techniques

The techniques can be used effectively to treat a wide variety of industrial effluents generated from many industrial processes. Evaporation technologies provide effective solutions to the problems of **disposal** of moderate quantities of effluent streams containing **high concentrations** of contaminants such as inks, oils, paints, colorants, organic solvents, glue residues, or even metals. Recovery of water for reuse may be possible. Industries which have used evaporation techniques successfully to treat their effluents include carton box manufacturing, newspaper industries, fllexographic printing, silk printing, offset web press printing, metals finishing, automotive parts industry, printed circuit boards manufacture, coolant manufacture and photographic shops,

Vacuum distillation is attractive to industries which aim to **recover** valuable chemical resources or adopt **zero-liquid discharge** option.

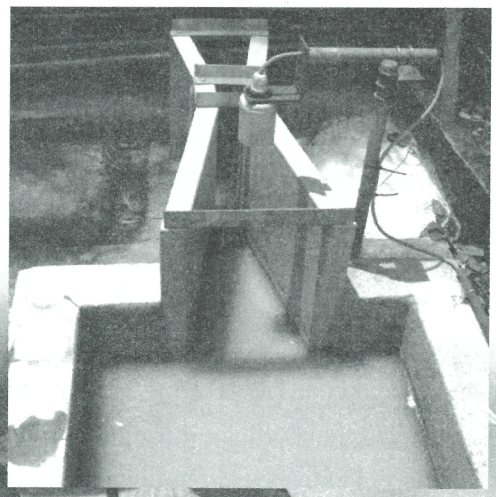
12.19.3 From the perspective of the DOE officer/inspector

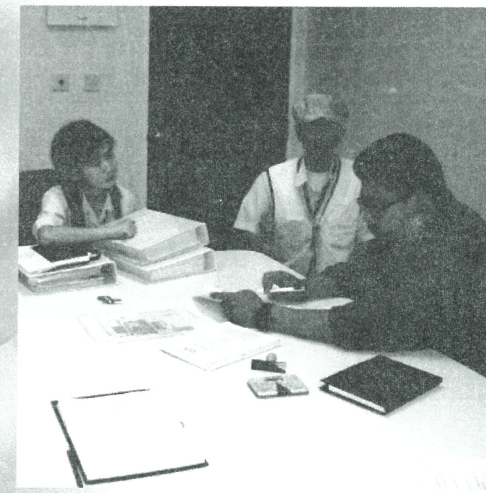
As a DOEofficer/ inspector you know that **temperature** and **pressure** are key parameters in the operation of mechanical evaporators, particularly vacuum distillation systems. The parameters need to be maintained within the design ranges. However, nowadays, evaporation systems are designed equipped with programmable logic controllers (**PLC**) and **data logging**

features which enable the systems to be operated unattended for a long period. **Foaming is** also a common problem in evaporation systems, which needs to be managed effectively, sometimes through the use of **antifoaming agents**. All these aspects are to be given attention during your inspection.

CHAPTER 13:

PERFORMANCE MONITORING OF COMMON PHYSICAL-CHEMICAL TREATMENT PROCESSES





CHAPTER 13:

PERFORMANCE MONITORING OF COMMON PHYSICAL-CHEMICAL TREATMENT PROCESSES

13.1 Performance monitoring of physical chemical treatment processes

The rationale, benefits and legal requirements of IETS performance monitoring have been discussed in Chapter 4. In this chapter, we will discuss how to conduct performance monitoring of the following physical chemical treatment processes commonly used for the treatment of industrial effluents:

neutralization and pH adjustment, chemical precipitation, coagulation, flocculation, flotation, two stage chromium treatment, alkaline chlorination for cyanide removal, ion exchange, activated carbon adsorption, media filtration, membrane filtration, and evaporation technique (vacuum distillation).

Although some physical-chemical treatment processes have well-defined **performance monitoring parameters,** several processes do not lend themselves to the conduct of performance monitoring, due to the **nature of physical/ chemical processes** involved. This fact is particularly true in the case of physical processes. In such cases, day to day monitoring takes the form of **operation and maintenance** (O&M) rather than performance/process monitoring per se. This is a major difference between the nature of performance monitoring of **biological treatment processes** compared to the monitoring of **physical-chemical treatment processes**. In physical treatment processes, O&M activities are more focused on the **"hardware"** aspects of the IETS operation, hence not covered in this Guidance Document or the syllabus of this course, which primarily concentrates on the **"software"** aspects.

13.2 Guidance Document on performance monitoring of industrial effluent treatment systems

The primary reference for the procedure to conduct IETS performance monitoring is the guidance document published by the DOE entitled **Guidance Document on Performance Monitoring of Industrial Effluent Treatment Systems.** The minimum specifications on IETS performance monitoring and record keeping requirements stipulated in the document must be adhered to by the industries.

13.3 Performance monitoring of neutralization and pH adjustment process

As discussed in Chapter 12, this is a process of adding **neutralizing chemicals** either an **acid** or a **base** to change the pH of a solution to a more acceptable range either for **direct discharge** to a public drain/watercourse or for **subsequent treatment** process. Once the neutralization system has been designed adequately and the amount of neutralization agent computed (In the case of manual process), the performance monitoring activity centers around the following tasks:

(i) Maintaining and calibrating the **pH meter** as per manufacturer's manual
(ii) Ensuring sufficient supply of **neutralizing agent** in the storage tank
(iii) Conducting **titration experiments** to determine/verify the amount of chemical needed and to calibrate the automatic instrumentation system or determine/adjust the correct setting of the dosing pump.
(iv) Ensuring the **desired pH** level is maintained at all time.

The pH adjustment process can be designed with **automatic pH control interlocked with chemical-dosing system**.

13.4 Performance monitoring of metal precipitation process

It was noted in Chapter 12 that **alkaline precipitation** of metals as **metal hydroxides** is the most common technology for removing metals from solution, before the effluent is discharged. The amount of reagent required to raise the pH of

the effluent to be treated to the desired level must be determined **experimentally**. Other methods of metal removal are via **sulfide or carbonate precipitation**. Similarly, the amount of chemicals required in the precipitation process must be decided based on experimental results. This aspect has also been dealt with thoroughly in the previous chapter.

Once the hydroxide precipitation system has been set up and established, performance monitoring routine will revolve around the same activities as in the case of monitoring neutralization/pH adjustment process, namely:

(i) Maintaining and calibrating the **pH meter** as per manufacturer's manual
(ii) Ensuring sufficient supply of **precipitating agent** in the storage tank
(iii) Conducting **jar test experiments** to determine/verify the amount of chemical needed and to calibrate the automatic instrumentation system or determine/adjust the correct setting of the dosing pump.
(iv) Monitoring and ensuring the **desired pH** level is maintained at all time.
(v) Monitoring the **metal concentration** in the influent to the precipitation tank and effluent from the tank/clarifier.

In sulfide precipitation process, performance monitoring involves the monitoring of pH of the process which needs to be maintained above a certain value to prevent evolution of toxic H_2S gas. Reagent demand is typically determined and monitored through a **specific-ion sulfide reference electrode pair**, which is set to a selected potential. Again, as in the case of pH adjustment, the precipitation process can be designed with **automatic chemical-dosing and pH control system**. In such a case performance monitoring of the process would be minimal.

13.5 Performance monitoring of two stage chromium removal process

As discussed earlier in Chapter 12, chromium in industrial effluents is commonly removed via a **two stage process** involving the **reduction** of chromium (6+) to chromium (3+) and then **precipitating** the chromium (3+) as chromium hydroxide. The first stage of the process is controlled by ensuring the pH of the solution is maintained at 2.0 or below and ORP of > + 250 mV. In the second stage pH is controlled at 8-9.

Similarly, in this process, once the system has been set up and established, performance monitoring routine will concentrate on such activities as:

(i) Maintaining and calibrating the **pH and ORP meters** as per manufacturer's manual
(ii) Ensuring **sufficient supply** of acid, reducing and alkaline agents in the storage tank
(iii) Calibrating/adjusting the correct **setting** of the dosing pumps.
(iv) Monitoring and ensuring the **desired pH and ORP** levels are maintained at all time.
(v) Monitoring the **chromium concentration** in the influent to the precipitation tank and effluent from the tank/clarifier.

For continuous operation, the precipitation process is commonly designed with **automatic chemical-dosing and pH/PRP control system**. In such a case performance monitoring of the process would be minimal.

13.6 Performance monitoring of alkaline chlorination for cyanide removal process

The alkaline chlorination as the process is commonly known, destructs cyanide **via two stage process** whereby the cyanide is firstly converted to **cyanate** and then the cyanate is oxidized to **carbon dioxide.** In the first stage the pH must be maintained at 11 or above and ORP between 325 mV and 400 mV. In the second stage the pH must be controlled at about 8.5 and ORP between 600 mV to 800 mV. Once established, the monitoring of the alkaline chlorination process is for the most part similar to the monitoring of chromium reduction process, namely:

(i) Maintaining and calibrating the **pH and ORP meters** as per manufacturer's manual
(ii) Ensuring sufficient **supply of hypochlorite** solution and alkaline agent in the storage tank
(iii) Calibrating/adjusting the correct **setting** of the dosing pumps.
(iv) Monitoring and ensuring the **desired pH and ORP** levels are maintained at all time.
(v) Monitoring the **cyanide concentration** in the influent to and effluent from the chlorination tank.

The alkaline chlorination process precipitation process is commonly designed with **automatic chemical-dosing and pH/PRP control system**.

13.7 Performance monitoring of ion exchange process

Ion exchange process removes specific metals from the effluent stream. The influent to the ion exchange column may be preceded by **pH adjustment**. In the operation of ion exchange column, one of the most important parameters to monitor is the onset of **breakthrough time**. Once established, the monitoring of the ion exchange process consists of the following:

(i) Maintaining and calibrating the **pH meter** as per manufacturer's manual
(ii) Monitoring the **pH of the influent** to the column
(iii) Monitoring the onset of breakthrough time either in the form of monitoring the **volumetric throughput**, **column usage time** or **effluent quality** (metal concentration)
(iv) Monitoring **effluent** conductance and /or pressure in the inlet and outlet of the column.

The aspect of the management of **regenerant effluent stream** must be addressed adequately. The regenerant stream is typically **treated separately** from the rest of other effluent streams because it is **highly concentrated** with the metal that has been removed from the effluent stream. Sometimes, the metal is plated out via the **electrowinning process.** The disposal or regeneration of **used ion exchange resins** needs to be managed in accordance with the requirements stipulated in the Scheduled Waste Regulations 2005.

13.8 Performance monitoring of activated carbon adsorption column

Just like the case of ion exchange columns, the monitoring of the operation of activated carbon columns involves the monitoring of the onset of **breakthrough time**. The breakthrough time is estimated at the design stage and monitored as treatment progresses. Primarily, the monitoring of the carbon column consists of:

(i) Monitoring the onset of breakthrough time either in the form of monitoring the **volumetric throughput**, **column usage time** or **effluent quality** (for example COD).

The disposal or regeneration of **used activated carbon** needs to be managed in accordance with the requirements laid down in the Scheduled Waste Regulations 2005.

13.9 Performance monitoring of coagulation and flocculation processes

As discussed in Chapter 12, coagulation is a charge neutralization process which requires **rapid mixing** while flocculation is a particle agglomeration process which **requires slow mixing**. The velocity gradient required (hence the paddle mixing speed) for each process has been determined and fixed at the **design stage**. The performance monitoring tasks at the operational stage includes the following:

(i) Observing **floc formation** on a routine basis and ensure that both the coagulation and flocculation processes happen satisfactorily
(ii) Conducting **jar test experiments** to determine/verify the amount of coagulant and flocculant needed and calibrate/adjust the correct setting of the dosing pump.
(iii) Monitoring and ensuring the **desired pH** is maintained at all time
(iv) Maintaining and calibrating the **pH meter** as per manufacturer's manual
(v) Ensuring sufficient **supply of coagulant and flocculant** in the storage tank

13.10 Performance monitoring of dissolved air flotation process

Dissolved air flotation (DAF) systems remove suspended solids or oil and grease. The performance monitoring of DAF process involves the following tasks:

(i) Monitoring **flowrate** of the inlet and recycle streams
(ii) Monitoring **suspended solids** (SS) or **oil and grease** (O&G) concentration in the inlet stream
(iii) Monitoring **operating pressure**
(iv) Observing/monitoring **speed** of the skimmer

Among the parameters above, pressure is the most important parameter to be monitored in order to compute the **A/S ratio**. Typically, the A/S ratio is maintained between 0.03 and 0.05 (by weight).

13.11 Performance monitoring of media filtration

Media filtration systems are designed to remove residual suspended solids. At the operational stage, performance monitoring tasks for media filters involves the following tasks:

(i) Monitoring effluent **flowrate**
(ii) Monitoring **differential pressure** between the upstream and downstream side of the filter
(iii) Ensuring **backwashing** process works properly.

Periodic **washing of filters** is necessary for removal of **accumulated solids**. **Backwash techniques** employed depend on several factors such as types of filters, design of filter media support and the availability of the necessary equipment.

13.12 Performance monitoring of membrane filtration

The purpose of membrane filters is also for removing residual **suspended solids** which are very fine and small in diameters. Performance monitoring of membrane filters is typically carried out by continuous monitoring the following operational parameters:

(i) **Flow** of the feed, filtrate and concentrate stream
(ii) **Pressure** of the feed, filtrate and concentrate stream
(iii) **Elapsed run time**
(iv) **Temperature** of the feed and filtrate
(v) **Flux**
(vi) **Recovery**
(vii) Trans-membrane **pressure** and specific ultrafiltration **resistance** (SUR) for UF filters.

Membrane fouling caused by excessive presence of suspended solids and organic contaminants is a common problem in the operation of membrane systems, hence needs to be closely monitored.

13.13 Performance monitoring of evaporation techniques

Evaporation techniques concentrate the contaminants present in effluents and produce water, which can be recycled, if required. Performance monitoring of mechanical evaporators including vacuum distillation systems involves continuous monitoring of the following:

(i) **Conductivity** of the process distillate.
(ii) **Vacuum pressure**
(iii) **Temperature**

Foaming is a common problem in the operation of evaporators due to dissolved or entrained gases which can be addressed by adding **antifoam chemicals** to the feed solution.

13.14 From the perspective of the DOE officer/inspector

As a DOE officer/inspector, you understand that what to look for in the inspection of physical chemical processes (PCPs) depends on the PCP itself. The **relevant parameters** concerned and other observations to be made during an inspection duty are summarized in Table 13.1 according to the PCP involved.

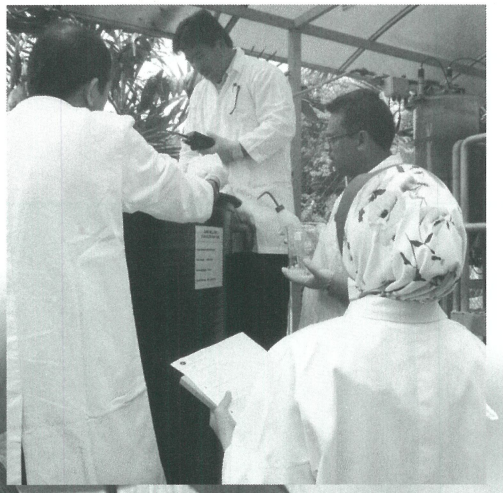
Table 13.1: Relevant PM parameters and observations to be made by inspectors according to different PCPs

PCP	Relevant PM parameter	Other observations necessary
EQ	Flowrate; temperature; pH	-
Neutralization	pH	Checking of chemical dosage; inspection of chemical dosing system
Coagulation, flocculation	pH	Checking of chemical dosage; inspection of chemical dosing system; observation of floc formation
DAF	Flow; recycle flowrate; pressure;; SS pr O&G; A/S ratio	checking of chemical dosage; inspection of chemical dosing system;
Hydroxide metals precipitation	pH	Checking of chemical dosage; inspection of chemical dosing system; metals (inlet and outlet)
Sulfide precipitation	pH;	Checking of chemical dosage; inspection of chemical dosing system
Carbonate precipitation	pH	Checking of chemical dosage; inspection of chemical dosing system
Ion exchange	pH; breakthrough time;	Checking of chemical dosage; inspection of chemical dosing system
Two stage chromium removal	pH; ORP	Checking of chemical dosage; inspection of chemical dosing system; chromium (inlet and outlet)

Alkaline chlorination for cyanide removal	pH; ORP; cyanide concentration	Checking of chemical dosage; inspection of chemical dosing system;
Media filtration	SS (inlet and outlet); differential pressure	-
Membrane filtration	Flux; recovery; trans membrane pressure; elapsed time; pressure (inlet, outlet); temperature (inlet and outlet)	-
Evaporation (vacuum distillation)	Flowrate; pressure; temperature	Observation of foaming
Activated carbon adsorption	Volumetric throughput, usage time, COD	-

CHAPTER 14:

MAINTENANCE OF PCP COMPONENTS AND PERFORMANCE MONITORING INSTRUMENTS





CHAPTER 14:

MAINTENANCE OF PCP COMPONENTS AND PERFORMANCE MONITORING INSTRUMENTS

14.1 Importance of IETS maintenance program

The importance of preparing and implementing an effective **preventive and corrective maintenance program** of the IETS components has been discussed in section 7.1. This is applicable to both BPs and PCPs.

14.2 IETS hardware components

Uninterrupted and smooth operation of physical and chemical treatment processes (PCP) depends on the **hardware components** of the PCP processes being maintained properly to prevent the occurrence of breakdown and malfunction. The PCP hardware can be categorized into two main groups as follows:

(i) Components that form the **building blocks** of the PCP such as reaction tanks, mixers, pumps, piping system, compressors, motors, auxiliary tanks, skimmers, and other associated equipment and parts such as chemical dosing systems, ejectors, valves, etc

(ii) **Performance monitoring equipment and instrumentation** systems such as, pH sensors and meters, redox meters, conductivity meters, pressure gages and temperature sensors.

To ensure smooth running and operation of both groups of the above hardware, hence the IETS itself, a well prepared and executed **preventive and corrective maintenance program** is required. As mentioned in section 7.2 the maintenance of the second group of hardware components is usually entrusted to the IETS team.

14.3 Common performance monitoring instruments used for monitoring physical-chemical treatment processes

Two of the most common instruments used in treatment of industrial effluents using physical-chemical processes are **pH** and **ORP** meter and less commonly, **temperature sensors** and **pressure gages**. The success of the treatment depends on the proper **functioning** of these meters and sensors to measure the PM parameters accurately. Proper functioning of the meters depends on their upkeep and calibration in accordance with the **manufacturer's instructions**. The importance of instrument maintenance cannot be over emphasized. Some important aspects of the maintenance and calibration of the meters are outlined below.

14.4 Maintenance of pH and Redox meters

14.4.1 Cleaning of probes

The same cleaning procedures are applicable to pH and ORP probes. Common probe problems are **fouling by precipitates** and **coating by oil and grease** (O&G) and precipitates of **metallic hydroxide**, **calcium** and **magnesium**.

Salts are readily removed by dipping a dry probe in a **concentrated hydrochloric acid** solution for two to three seconds. The probe is then rinsed with clean water and allowed to soak in the water for about five minutes before calibration.

O&G may be removed by cleaning the probe with 100 percent **isopropanol**. If this is not successful other options include scrubbing the probe with a dishwashing liquid using a soft brush or soaking in a 33 percent sodium hydroxide or dipping the probe in a concentrated hydrochloric acid solution.

14.1.2 Calibration of probes

pH probes are calibrated according to the manufacturer's instructions, typically by using **two "standard" buffer solutions**. The standard buffer has a pH of 7.0 while the other buffer used as the "slop" buffer has a pH of either 4.0 or 10.0. The 10.0 pH buffer is used if the pH probe will be used in alkaline environment such as in metal precipitation process or cyanide destruction process. The 4.0 pH buffer is used if the pH probe will be used in acidic environment such as in chrome reduction process.

ORP probes are calibrated using only **one standard solution** which is prescribed by the instrument manufacturer. The calibration procedure must follow the manufacturer's instructions. The participants will perform calibration of pH and ORP probe in the laboratory session. In the factory's premise, maintenance of instruments including the calibration of pH and ORP sensors may not be one of the duties of the participants, but as an IETS supervisor, the participants must appreciate its importance and ensure that, the maintenance is carried out.

14.5 Maintenance of temperature sensors

Thermocouples are the most widely used temperature sensors particularly in industrial applications**.** Deterioration of thermocouples may occur due to **contamination** from the environment. Although there are no maintenance functions available on thermocouples **scheduled calibration checks** are recommended

14.6 Maintenance of conductivity meters

Conductivity meters must be **calibrated** to a **standard solution** before using. A standard should be chosen that has the approximate conductivity of the effluent to be measured. A soiled electrode must be cleaned before use by using **hot water** and a mild detergent. Organic matter can be cleaned by using **acetone** and algae,

bacteria or mold by using **hypochlorite** solution. A cotton bud may be used for the cleaning task.

14.7 Maintenance of pressure gages

Periodic **inspection**, **cleaning** and **recalibration** is a standard practice and should be performed according to the manufacturer's recommendation.

14.8 From the perspective of DOE officer/inspector

As a DOE officer/inspector you understand that maintenance of equipment and instrumentation system is crucial to the smooth and uninterrupted operation of the IETS. During your inspection duty you should check **records of PM instrument maintenance** and **calibration** which should adhere to the manufacturers' recommendations.

CHAPTER 15:

ANALYSIS OF INDUSTRIAL EFFLUENTS FOR PERFORMANCE MONITORING OF PHYSICAL CHEMICAL TREATMENT PROCESSES



CHAPTER 15:

ANALYSIS OF INDUSTRIAL EFFLUENTS FOR PERFORMANCE MONITORING OF PHYSICAL CHEMICAL TREATMENT PROCESSES

15.1 Typical measurements in PCP

Under Industrial Effluent Regulations 2009, IETS performance monitoring records are required to be maintained to comply with the requirements stipulated in the **Guidance Document on Performance Monitoring of Industrial Effluent Treatment Systems**. This chapter discusses the following activities typically performed by the IETS team to operate and monitor the physical chemical treatment processes (PCPs):

(i) Chemical stock preparation
(ii) Jar test experiments

The measurement of other parameters such as flowrate, pH, oxidation reduction potential (ORP) and chemical oxygen demand (COD) have been discussed in Chapter 10.

15.1 Chemical stock preparation

Examples of chemicals commonly used in IETS-PCPs are sulfuric acid and sodium hydroxide. Sodium metabisulfite is typically used for chromium reduction. These chemicals need to be prepared with a specific concentration typically used in the operation of PCPs from the stock solutions.

PCP operations may also involve preparing polymer and flocculant solutions with a specific concentration (%) from the powdered and liquid forms. These chemical formulations are typically used in practice in the industries for the coagulation and flocculation process.

15.2 Jar test experiments

Jar test experiments are typically conducted to determine the **optimum dose of coagulants** and **flocculants** to remove suspended solids which are either present in the raw effluents or formed from chemical precipitation process.

The jar test experiments normally involve a two stage experiments which are described below.

(i) The coagulant/flocculant dose is fixed while the pH is varied and the resultant effluent quality characterized by either SS concentration or turbidity is measured. The pH which gives the **best effluent quality** is noted and is used in the next stage of the experiment

(ii) The pH is fixed while the coagulant/flocculant dose is varied and the resultant effluent quality characterized by either SS concentration or turbidity is measured.

The dose which gives the best effluent quality is noted and this is the **optimum dose** of the coagulant/flocculant to be used in **actual field application**.

15.3 Determining the chemicals required for a two stage metal removal process (Removal of chromium)

Sometimes experiments may need to be conducted to determine the dose of chemicals required for the removal of chromium (VI) by a **two stage process**. In the first stage chromium (VI) is reduced to chromium (III by firstly adding acid to adjust the pH of the solution to 2.0. Then, sodium metabisulfite is added until the **ORP** reaches 250 mV to 350 mV. For the second step to precipitate chromium (III) as hydroxide, sodium hydroxide is added until **pH** of the solution reaches 9.0. The amounts of chemicals used are then noted. Coagulant and polymer may be added to improve the removal of chromium.

15.4 Scaling up

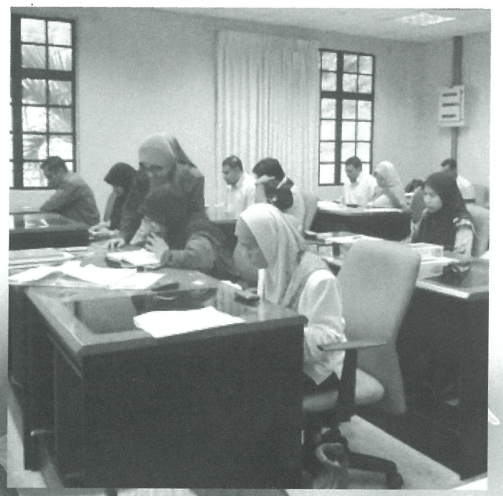
Scaling up is the process of utilizing the information obtained in the laboratory experiments to the **actual requirements** of applications in the field. In PCP treatment applications, in particular, scaling up refers to the use of **jar test data** on coagulant and flocculant dosage to suit the **actual conditions in the filed,** either for a bigger volume of effluent (batch treatment) or for an effluent which flows on a continuous basis. Examples on **scale up computations** are illustrated in Chapter 16.

15.5 From the perspective of DOE officer/inspector

As a DOE officer/inspector you understand that raw effluent quality does not remain constant all the time. Doses of chemical required for various treatment purposes need to be checked from time to time to ensure optimum amounts are delivered by the chemical dosing systems. Jar test experiments are typically conducted and the information obtained is scaled up for field applications.

CHAPTER 16:

PCP MATHS





CHAPTER 16:

PCP MATHS

16.1 Typical calculations for operation and maintenance of PCP

This chapter is dedicated to the **calculations/computations** that are commonly associated with the operation and maintenance of physical-chemical treatment processes (PCP). Some of the calculations are follow-up computations based on information obtained from **laboratory experiments** scaled up for practical applications on a real IETS **operational setting**.

The following paragraphs illustrate the computations commonly encountered in PCP operations, namely:

(i) Flowrate
(ii) Detention time
(iii) Discharge rate
(iv) Chemical preparation and dose
(v) Chemical feeder and pump setting
(vi) Reagent requirements for neutralization and pH adjustment
(vii) Caustic requirements for metal hydroxide precipitation

16.2 Flowrate

Formula for calculating flowrate is:

$$\text{Average daily flow} = \frac{\text{Totalizer reading}_2 - \text{Totalizer reading}_1}{T_2 - T_1}$$

Where T is time the totalizer reading was taken.

Typical units:

Totalizer reading : m^3; T: h

Example 1:

Calculate the average daily flow in m^3h^{-1} and m^3d^{-1} if the reading on the totalizer on the flow meter at 8.00 am was 15,000 m^3 and at 6.00 pm 20,000 m^3

Answer:

Average daily flow $= \frac{20000\ m^3 - 15{,}000\ m^3}{(8\ am - 12\ noon)\ (12\ noon - 6\ pm)\ h}$

$= \frac{5000}{10} = 500\ m^3h^{-1}$

$= 500 \times 24\ m^3d^{-1}$

$= 12{,}000\ m^3d^{-1}$

16.3 Detention time

Formula for calculating Detention Time is:

$$\text{Detention time (D.T.)} = \frac{\text{Tank volume (V)}}{\text{Flow (Q)}}$$

Typical units:

D.T.: h; V : m^3; Q : m^3d^{-1}

Example 2:

Calculate the Detention Time in hour given the following:

V = 10 m^3

Q = 100 m^3d^{-1}

Answer:

$$\text{Detention Time} = \frac{10\ m^3}{100\ m^3 d^{-1}}$$

$$= 0.1\ d$$

$$= 0.1 \times 24 = 2.4\ h$$

16.4 Discharge rate

Formula for calculating discharge rate is:

$$\text{Discharge} = \frac{\text{Volume}}{\text{Time}}$$

Typical units:

Discharge: m^3h^{-1}; Volume : m^3; Time : h

Example 3:

An equalization tank contains 500 m^3 of effluent to be treated. Calculate the discharge rate in m^3h^{-1}, if the effluent is to be released from the tank at a constant rate during a 5 hours treatment period.

Answer:

$$\text{Discharge rate} = \frac{500\ m^3}{5\ h}$$

$$= 100\ m^3h^{-1}$$

16.5 Chemical concentration

Meaning of %

Concentration can be expressed in % or mg/L

A 1% solution of a chemical means that 1 g of the chemical is dissolved in 100 mL of solution.

$$1\ \% = \frac{1\text{g}}{100\text{ mL}} = \frac{1000\text{ mg}}{100\text{ mL}} \times \frac{1\text{L}}{1000\text{ mL}}$$

$$= 10{,}000\text{ mg/L}$$

Therefore: 1% = 10.000 mg/L

If two solutions of different concentration (%) are mixed, the concentration (%) of the resulting mixture can be computed as follows:

$$\text{Resultant mixture (\%)} = \frac{V_1 \%_1 + V_2 \%_2}{V_1 + V_2}$$

Example 4:

If 20 m^3 of 1% sodium hydroxide is mixed with 10 m^3 of 2%, what is the concentration (%) of the resulting mixture?

Answer:

$$\text{Resultant mixture (\%)} = \frac{(20 \times 1) + (10 \times 2)}{20 + 10}$$

$$= \frac{40}{30}\ \%$$

$$= 1.3\ \%$$

Converting % to mg/L

Recall that 1% = 10,000 mg/L; therefore, to convert % to mg/L, simply multiply the % by 10,000. Thus the formula is:

Concentration (mg/L) = % x 10,000

Example 5:

Calculate the concentration of sodium hydroxide in mg/L if the % is 4%.

Answer:

1% = 10, 000 mg/L
4% NaOH = 4 x 10,000 mg/L
= 40,000 mg/L

16.6 Chemical preparation

Many a time you may need to prepare chemical solutions from stock solutions purchased from chemical suppliers. An example would be to prepare a coagulant solution for jar test experiments with a certain % (weight/volume) from a concentrated stock coagulant solution. You need to determine the volume of stock solution required to prepare a solution with the required dose.

Chemical preparation from liquid stock solution

Formula for calculating the volume of stock solution is:

Volume of stock solution (mL) =

$$\frac{\text{dose of chemical solution required (\%w/v) x final volume (mL)}}{\text{SG x stock solution strength (\%w/v)}}$$

Where SG = specific gravity of stock solution

Example 6:

Determine the volume of stock solution of alum (SG = 1.3; 46.5 % (w/v)) required to prepare 1.0 L of 1% alum solution to be used in the coagulation process

Answer:

Using the formula above, Volume of stock solution (mL) =

$$\frac{1\ ((\%w/v) \times 1000\ mL}{1.3 \times 46.5\ (\%w/v)}$$

$$= 16.5\ mL$$

What you need to do is to take 16.5 mL of the stock solution and add (1000 -16.5= 983.5 mL) of distilled water to make up 1.0 L of the solution.

Coagulant preparation from powdered form

Sometimes you need to prepare a solution from a "dry chemical" which is purchased from the supplier in powdered form. The chemical could be a polymer, a coagulant (e.g. ferric chloride) or a pH adjustment chemical which comes in powdered form.

Formula for calculating the weight of dry chemical required is:

$$\text{Mass of dry chemical (g)} = \frac{\text{chemical solution dose required (\%w/v)} \times \text{final volume (mL)}}{100\ (\%)}$$

Example 7:

Determine the mass of dry chemical required to make up 1.0 L of 1% solution.

Answer:

$$\text{Mass of dry chemical (g)} = \frac{1\ (\%) \times 1000\ mL}{100\ (\%)}$$

$$= 10\ g$$

What you need to do is to take 10 g of the dry chemical and add enough distilled water to make up 1.0 L of solution.

Example 8:

You have estimated that you required 50 kg of a pure chemical. The available purity or percent active chemical as stated on the chemical container label is 95 percent; calculate the weight in kg of the chemical from the container to prepare the required percent solution.

Answer:

Actual weight of chemical required

$$= \frac{\text{estimated weight of pure chemical}}{\text{Purity}}$$

$$= \frac{50 \text{ kg}}{0.95}$$

$$= 52 \text{ kg}$$

Producing a solution with desired %:

The formula is:

$$\%\ \text{chemical required} = \frac{(\text{weight of chemical})\ (100\%)}{\text{weight of water}}$$

Example 9:

Calculate the weight of hydroxide required to be added to 10 m^3 of water to produce a 4% hydroxide solution. Density of water = 1000 kgm^{-3}

Answer:

There are several ways to calculate the weight of hydroxide required. One of the methods is illustrated below.

mg/L = % x 10, 000

4% NaOH = 40,000 mg/L

1 m^3 = 1000 L; 10 m^3= 10,000 L

Therefore wt of NaOH in 1000L = 40,000 mg/L x 10,000 L

= 400 x 10^6 mg

= 400 kg

Example 10:

If the polymer tank has the following dimensions

L	=	1.0 m
W	=	1.5 m
D	=	1.0 m

Calculate the weight of polymer in kg to be added to the tank to produce a polymer concentration of 2 mg of polymer per mL. Note that 1 mg/mL = 1 g/L = 0.1% polymer solution.

Answer:

Volume of polymer tank	=	1.0 x 1.5 x 1.0 m^3
V	=	1.5 m^3
1 m^3	=	1000 L
\ V	=	1,500 L
Polymer, g	=	(polymer concentration, mg/L) (Volume, L)
	=	(2 g/L) x (1,500 L)
	=	3000 g
	=	3 kg

Example 11:

If you were to prepare 2000L of polymer of 0.5% polymer solution, how many kg of polymer do you need?

Answer:

Polymer required = $\frac{2000\ L \times 0.5\%}{100\%}$

= 10 kg

Or, 1% = 10,000 mg/L

0.5% = 0.5 x 10,000 = 5000 mg/L

= 5 g/L

= 5000 mg/L = 5 g/L

In 2000 L, wt of polymer = 5 g/L x 2000 L

= 10 kg

16.7 Chemical feeder setting

If the chemical feeder setting is based on kg of chemical per day or kg of chemical per hour, the formula is:

Chemical feeder setting, kg/d = (Flow, m^3/d) (Dose, mg/L)/1000

Or

Chemical feeder setting, kg/h = $\frac{\text{(Flow, } m^3\text{/d) (Dose, mg/L)/1000}}{24\ h/d}$

Example 12:

Calculate the chemical feeder setting in g/h for treating an industrial effluent at 3 m^3/h that requires the chemical to be dosed at 10 mg/L

Answer:

Chemical feeder (g/h) = 3 m^3h^{-1} x 10 mg/L^{-1}

= 30 gh^{-1}

16.8 Pumping rates

Example 13:

Calculate the pump feed rate in m^3/d if the pump delivers 200 mL in 2 minutes

Answer:

$$\text{Pump feed rate} = \frac{200\ mL}{2\ min}$$

$$= 100\ \frac{mL}{min} \times \frac{1L}{1000\ mL} \times \frac{1.m^3}{1000\ L} \times \frac{24 \times 60\ min}{1d}$$

$$= 0.144\ m^3d^{-1}$$

Example 14:

Calculate the volume of industrial effluent (in cubic meters) delivered by a pump to a coagulation tank if the pumping rate is 20 L/h for 10 hrs.

Answer:

$$\text{Volume} = 20\ L/h \times 10\ h$$

$$= 200\ L \times \frac{1\ m^3}{1000\ L}$$

$$= 0.2\ m^3$$

16.9 Polymer and coagulant requirements

Formula for calculating polymer dose (mg per min) is:

= (flow, L/min) x (dose, mg/L)

Example 15:

From laboratory experiment, you require a polymer dose of 0.6 mg/L for the treatment of an industrial effluent. If the specific gravity of the 0.5% liquid polymer

is 1.0 and the effluent flow is 100 m^3/h, calculate the polymer feed rate of the feeder in mL per min

Answer:

We need to calculate the polymer feed rate through a three step process as follows:

(i) Polymer dose (mg/min) = 100 m^3/h x h /60 min x 0.6 mg/L x 1000m^3/L

= 1000 mg/min

(ii) Polymer solution (mg/mL)

1% = 10,000 mg/L

0.5% ,polymer concentration = 0.5 x 10,000 = 5000 mg/L = 5 mg/mL

(iii) Polymer feedrate = $\frac{\text{dose, mg/min}}{\text{polymer solution, mg/mL}}$

$= \frac{1000 \text{ mg/min}}{5 \text{ mg/mL}}$

= 200 mL/min

Example 16:

From jar test experiment you have found that the optimum coagulant dose is 10 mg/L. The effluent flow is 480 m^3/d and the liquid coagulant purchased contains 200 mg per mL of liquid solution. Determine the setting on the liquid coagulant feeder, in mL per min

Answer:

Chemical feed rate = $\frac{\text{(flow, } m^3/d\text{) (dose, mg/L)}}{\text{(chemical concentration, mg/mL)}}$

Recall: dose determined from experiment = 10 mg/L

Coagulant feed rate = $\frac{480\ m^3/d \times 10\ mg/L}{200\ mg/mL \times 1000\ mL/1L}$

$= \quad 0.024 \times 10^{-3} \ m^3/d$

$= \quad 0.024 \times 10^{-3} \ \frac{m^3}{d} \times \frac{1d}{24h} \times \frac{1h}{60 \ min} \times \frac{1000 \ L}{m^3} \times \frac{1000 \ mL}{1 \ L}$

$= \quad 16.7 \ mL/min$

16.10 Reagent requirements for neutralization and pH adjustment

For neutralization and pH adjustment requiring acid, the following formulae are usually required:

Millequivalent = (mL) (N)

(effluent normality, N) = $\frac{\text{(acid volume, mL) (acid normality, N)}}{\text{(sample volume, mL)}}$

Effluent normality, N is obtained from laboratory experiment where:

acid volume, mL is the volume of acid used in the experiment;
acid normality, N is the normality acid used;
sample volume, mL is the volume of sample used in the experiment.

For batch treatment:

(acid, mL) (acid, N) = (effluent, mL) (effluent, N)

Acid, mL is the volume of acid required in actual application (treatment case);
Acid, N is the normality of acid used in actual application (treatment case);
Effluent, mL is the volume of effluent to be treated (treatment case);
Effluent, N is the normality of effluent obtained in the laboratory experiment.

For continuous treatment:

(acid flow, mL/s) (acid, N) = (effluent flow, mL/s) (effluent, N)

N is normality which is abbreviated as N. mL represents the volume which can be replaced by L

or any other units of volume.

Acid flow, mL/s is the flowrate of acid required for the treatment (treatment case);
Acid, N is the normality of acid used in actual application (treatment case);
Effluent, mL/s is the flowrate of effluent to be treated (treatment case);
Effluent, N is the normality of effluent obtained in the laboratory experiment.

For neutralization and pH adjustment requiring caustic, the formula below is commonly used when caustic information is in the form of %:

Treatment scenario		Sample scenario
$\frac{(\text{caustic, mL})\,(\text{caustic, \%})}{(\text{effluent, mL})}$	=	$\frac{(\text{caustic, mL})\,(\text{caustic, \%})}{(\text{sample, mL})}$

The left hand side of the above equation is for "treatment scenario" while the right hand side is for "sample scenario". mL can be replaced by L or any other units of volume

Example 17:

A factory generates an effluent which requires only neutralization step before the effluent can be discharged to the public drain. If the effluent is to be treated on a batch mode, calculate how many liters of 2 N sulfuric acid are required to neutralize the effluent to a pH of 7.0. Other information is given below:

- A 50 mL sample of effluent requires 8.0 mL of 0.5 N sulfuric acid
- Volume of effluent to be treated is 5 m^3

Answer:

effluent N = $\frac{\text{(acid, mL) (acid, N)}}{\text{(sample, mL)}}$

= $\frac{\text{(8.0 mL) (0.5N)}}{\text{50 mL}}$

= 0.08N

For batch treatment:

(acid, mL) (acid, N) = (effluent, mL) (effluent, N)

Therefore:
Let us work in L instead of mL

(acid, L) = $\frac{\text{(effluent, L) (effluent, N)}}{\text{(acid, N)}}$

= $\frac{\text{(5000 L) (0.08N)}}{\text{2 N}}$

= 200 L

Example 18:

You are treating a metal-laden effluent on a batch basis via the hydroxide precipitation process. The pH of the solution needs to be raised from 6.0 to 10.0 using a 4% caustic. Given the following, calculate the weight in kg of the caustic required to treat 10 m^3 of effluent. 50 mL sample requires 10 mL of 1% caustic to raise the pH from 6.0 to 10.0

Answer:

(Caustic volume for treatment) (% caustic for treatment)/ Effluent volume for treatment =

(Caustic volume for sample) (% caustic for sample)/sample volume
The formula can be abbreviated as:

$(C_t)(\%_t)/V_t = (C_s)(\%_s)/V_s$
$(C_t) = (C_s)(\%_s)/V_s \times V_t/(\%_t)$

$$C_t = \frac{(10{,}000 \times 10^3 \text{ mL})(1)}{(50 \text{ mL})} \quad \frac{(10 \text{ mL})}{(4)}$$
$$= 500{,}000 \text{ mL}$$
$$= 500 \text{ L}$$

Weight in kg :

1% = 10,000 mg/L
4% = 40,000 mg/L
1L = 40,000 mg = 40 g
500L = 500 x 40 = 20,000g = 20kg

Example 19:

An industrial effluent is pumped from an equalization tank to a neutralization tank at a flowrate of 10 L/s. The results from lab tests show that a 50 mL sample of the effluent requires 5.0 mL of 0.05 N sulfuric acid to lower the pH from 10.0 to 7.0. Determine the setting in liters per minute on a chemical feed pump which is pumping 2 N sulfuric acid to the neutralization tank.

Answer:
Same calculation steps as in question 18, but the answer required is in L/min

$$\text{effluent N} = \frac{(5.0 \text{ mL})(0.05 \text{ N})}{50 \text{ mL}}$$
$$= 0.005 \text{ N}$$
$$\text{acid feed required} = \frac{(\text{effluent, L/min})(\text{effluent, N})}{(\text{acid, N})}$$

$$= \frac{(10\ \text{L/s} \times 60\ \text{s/min})\ (0.005\ \text{N})}{2\ \text{N}}$$

$$= 1.5\ \text{L/min}$$

Example 20:

In a laboratory experiment to remove a metal via the hydroxide method, a 50 mL sample was found to require 10 mL of 1% caustic to raise the solution pH from 6.0 to 10.0 to precipitate the metal from solution. Calculate the volume in L of the 5% caustic required to treat 10 m^3 of effluent.

The formula, (based on simple ratios) commonly used is:

(Caustic volume for treatment) (% caustic for treatment)/ Effluent volume for treatment =
(Caustic volume for sample) (% caustic for sample)/sample volume

Answer:

Use the same formula as in example19:
$(C_t) = [(C_s)(\%_s)/V_s] \times [V_t/(\%_t)]$

$$\text{Caustic volume for treatment} = \frac{(10{,}000\ \text{L})\ (10.0\ \text{mL})\ (1)}{(50\ \text{mL})\ (5)}$$

$$= 400\ \text{L}$$

Table 16.1 gives a summary of formulae that are commonly used for computations in physical chemical treatment processes (PCP).

Table 16.1: Summary of typical formula for PCP computations

Computation for	Formula
Average daily flow	Average daily flow = $\frac{\text{Totalizer reading}_2 - \text{Totalizer reading}_1}{T_2 - T_1}$
Detention time (D.T.)	Detention time (D.T.) = $\frac{\text{Tank volume (V)}}{\text{Flow (Q)}}$
Discharge _	Discharge = $\frac{\text{Volume}}{\text{Time}}$
Chemical concentration, mg/L	1% = 10.000 mg/L
Concentration of resultant mixture (%)	Resultant mixture (%) = $\frac{V_1 \%_1 + V_2 \%_2}{V_1 + V_2}$
Volume of stock solution , mL	Volume of stock solution ,mL = $\frac{\text{dose of solution required (\%w/v) x final volume (mL)}}{\text{SG x stock solution strength (\%w/v)}}$
Mass of dry chemical (g)	Mass of dry chemical ,g = $\frac{\text{solution dose required (\%w/v) x final volume (mL)}}{100\ (\%)}$
Actual weight of chemical required	Actual weight of chemical required = $\frac{\text{estimated weight of pure chemical}}{\text{Purity}}$
Producing a solution with desired %:	% chemical required = $\frac{\text{(weight of chemical) (100\%)}}{\text{weight of water}}$
Chemical feeder setting	Chemical feeder setting, kg/d = (Flow, m^3/d) (Dose, mg/L)/1000 Or in kg/h = $\frac{\text{(Flow, } m^3/d\text{) (Dose, mg/L)/1000}}{24\ h/d}$

Polymer dose, mg /min	Polymer dose, mg /min = (flow, L/min) x (dose, mg/L)
Chemical feed rate, mL/min	Chemical feed rate ,mL/min = $\frac{\text{(flow, m}^3\text{/d) (dose, mg/L)}}{\text{(chemical concentration, mg/mL)}}$
Caustic volume, mL	$\frac{\text{(caustic for trentment, mL) (caustic for teratment, \%)}}{\text{(effluent volume, mL)}}$ $\frac{\text{(caustic for sample, mL) (caustic for sample, \%)}}{\text{(sample volume, mL)}}$
Effluent normality, N	(effluent normality, N) = $\frac{\text{(acid volume, mL) (acid normality, N)}}{\text{(sample volume, mL)}}$
For continuous treatment: Acid flow, mL/s	(acid flow, mL/s) (acid, N) = (effluent flow, mL/s) (effluent, N)
For batch treatment Acid, L	(acid, L) = $\frac{\text{(effluent, L) (effluent, N)}}{\text{(acid, N)}}$
Caustic volume, C_t	$(C_t) = [(C_s)(\%_s)/V_s] \times [V_t/(\%_t)]$

16.11 From the perspective of DOE officer/inspector

As a DOE officer/inspector you understand that these are simple computations necessary for the operation of PCPs. These computations are routinely made by the IETS team and based on them, **operational changes** are made to the IETS to ensure IETS performance is maintained, hence complaint effluent produced on a sustained basis.

CHAPTER 17:

DATA ANALYSIS AND INTERPRETATION OF PCP PERFORMANCE MONITORING DATA





CHAPTER 17:

DATA ANALYSIS AND INTERPRETATION OF PCP PERFORMANCE MONITORING DATA

17.1 Data treatment

There are several ways of treating and analyzing the performance monitoring (PM) data of PCPs obtained either from measurements conducted in the **laboratory**, **instrument readings**, or by using **portable instruments** or **on line instrumentation** system. Whatever the case is, there are certain common ways of handling the PM data that are appropriate for making useful interpretation for the purpose of IETS operation. The data handling techniques are discussed in the following paragraphs.

17.2 Data tabulation

The **Guidance Document on IETS Performance Monitoring (GD2)** issued by the Department of Environment prescribes the tables/log sheets to be used by field technicians to record their in-situ measurements and instrument readings of PCP processes (BP). These are shown in Appendix A, D, E, F, G, H, I and J to the GD2. The tables/log sheets can be modified to suit individual industry's situation provided that the basic elements in the original tables are maintained.

17.3 Comparing the measured data with the recommended ranges

In physical chemical treatment processes, the data obtained from performance monitoring activities (in-situ measurements, instrument reading, laboratory measurements/analysis) depends on the type of **unit operations** and **unit processes**. But, unlike chemical unit processes, physical unit operations usually do not have clearly defined performance monitoring parameters. The performance monitoring

data of physical chemical processes include: **flowrate, T, pH, ORP, pressure, COD, metal concentration, color, chemical dosing rate, metering pump setting**, and **observation of floc formation**, Occasionally, **jar test experiments** are conducted to determine the optimum coagulant or flocculent dosing especially if new chemicals are being tested. The task of an IETS supervisor in the monitoring of the operation of IETS-PCP is not as demanding as in the monitoring of IETS-BP because in the former, all that is required is to compare the data obtained directly with the **recommended ranges** or **set points**.

Additionally, it is also a recommended practice that the supervisor sets a more **conservative value** for each parameter to serve as a "**warning level**" to alert the IETS operators to initiate response actions when the "warning level" is reached. The **recommended ranges** for most of the performance monitoring parameters have been highlighted in chapter 13 and throughout this course. The set points typically refer to the values specified for chemical dosing metering pumps to deliver a certain amount of chemical.

17.4 Range control charts

Range control charts can be easily plotted by using a statistical package commonly available on a personal computer for the following parameters: **pH, ORP, T, pressure, conductivity, COD and metal concentration.** These are performance monitoring parameters for physical chemical processes (PCP) most commonly found in industrial premises in Malaysia. The importance of these parameters is summarized in Table 17.1 below.

Table 17.1: Importance of various parameters for PCP

Parameter	Important for .....
T	Cooling ponds; Evaporation (distillation) for removal of various contaminants
Pressure	Media and membrane filtration for SS removal; DAF for SS and O&G removal: Evaporation (distillation) for removal of various contaminants
Conductivity	Membrane filtration for SS removal
pH	Neutralization, Metal precipitation as hydroxide including chromium (III); Coagulation for SS removal
ORP	Reduction of chromium from (VI) to (III); Alkaline chlorination for cyanide removal
COD	Activated carbon adsorption, Compliance with discharge standards
Metal Concentration	Ion exchange and hydroxide precipitation for metals removal; Compliance with discharge standards

Examples of the ranges for the control charts are given below.

Two stage chromium removal system

pH in the first tank (note: lower pH is better):

lower range =1.5,; upper range = 2.5

ORP in the first tank (note: lower ORP is better):

lower range =200mV,; upper range =250mV

pH in the second tank (note: higher pH is better):

lower range = 8.5; upper range = 10.0

Chromium in the final effluent

Cr (6+): upper range = 0.01 mg/L (standard is 0.05 mg/L)

Cr (3+): upper range = 0.005 mg/L (standard is 0.02 mg/L)

The industries may set **more conservative control levels** to act as waning or action level for their IETS staff to respond to different situations that they may encounter

in the day to day operation of the IETS. These **alarm levels** may physically be displayed as "warning lights" at conspicuous locations in the IETS, or a "flashing light" on computer screen or may trigger a message (email or sms) to be sent to the relevant IETS personnel.

17.5 Mainstreaming of IETS agenda through IETS status report

As discussed in section 11.5, the competent person and the IETS team must make an effort and establish effective procedure to make their presence on the premise felt by the organization. This can be accomplished by setting up a **reporting mechanism** where **status reports** are prepared on a scheduled basis and sent to all relevant **key personnel** within the industry organization. It is recommended that a **summary report** is submitted to the performance monitoring committee or management to summarize the findings/observations based on the data collected. Such a report which can be prepared on a **daily or shift basis** may look like the one illustrated in Fig. 17.1.

Chromium Hydroxide Precipitation

Findings

Based on the performance monitoring conducted today (March 16, 20010) from 8 a.m. to 4..p.m and the data collected, the following conclusions can be made about the IETS-PCP:

(a) The IETS was functioning in good working conditions with the discharge of effluent complying with all the parameters stipulated in Standard B, IIERs..
(b) The pH values in the first tank and the second tank were maintained according to the set points all the time
(c) The ORP values in the first tank were maintained at the set point all the time
(d) The following metals: Cr (6+), and Cr (3+) concentrations were well below the discharge standards

Recommendations

(a) The setting on the chemical dosing pump needs to be checked to ensure it is delivering the correct dosing rate

Prepared by IETS technician/operator: ……..… Checked by competent person…….....……
Signature……. Signature…….
Date & Time……...…… Date & Time……

Fig. 17.1: Example of Daily/Shift Report

Ii is common for some industries to conduct **shift** or **morning meetings** where the status of operation of relevant sections/units in the industry is discussed. The subject matter discussed includes the **status of IETS performance**. This practice is highly recommended. A **one page daily /shift report** summarizing the IETS performance can be prepared. The report can take the form of **graphical plots** of all relevant performance monitoring parameters with definitive statements whether the parameters are within the **acceptable ranges** hence the IETS is performing in satisfactory fashion or otherwise. In the case where the parameters are not within the recommended ranges, the problem needs to be highlighted and effective corrective action identified and agreed on. Another recommended practice is to prepare a one to two page **monthly summary report** (typically in the form of **graphical plots** too) of the PM data to be sent to the relevant factory personnel including the top management. An example of such a report is given in Fig. 17.2.

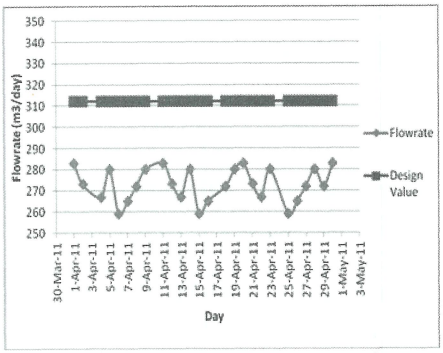


Fig 1: Graph of influent flowrate versus time

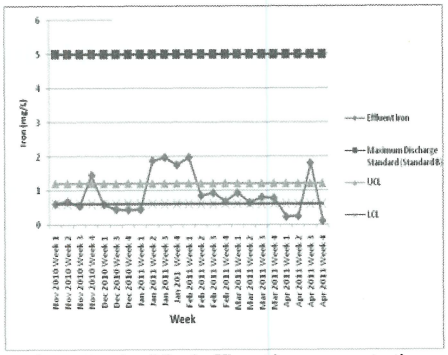


Fig 2: Graph of final effluent iron concentration versus time

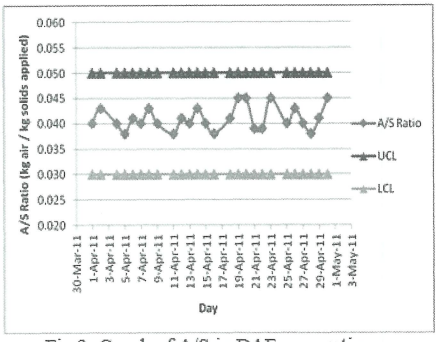


Fig 3: Graph of A/S in DAF versus time

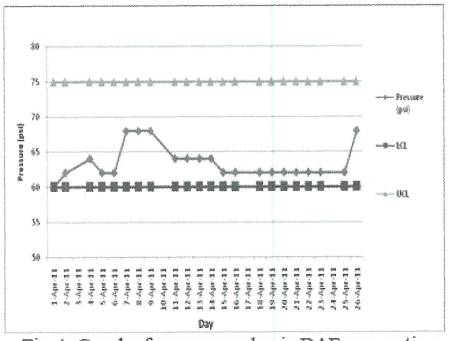


Fig 4: Graph of pressure value in DAF versus time

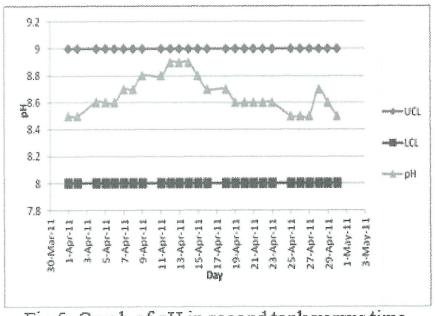


Fig 5: Graph of pH in second tank versus time (chromium hydroxide removal)

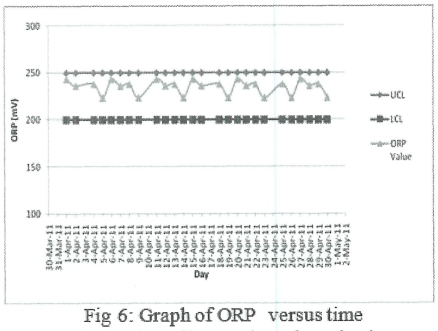


Fig 6: Graph of ORP versus time (reduction of hexavalent chromium)

Conclusions

All PM parameters were within the acceptable ranges. The final effluent quality complied with the discharge standards for all parameters.

Competent person…….... Signature…… Date…….

Fig. 17.2: Example of Monthly IETS Status Report

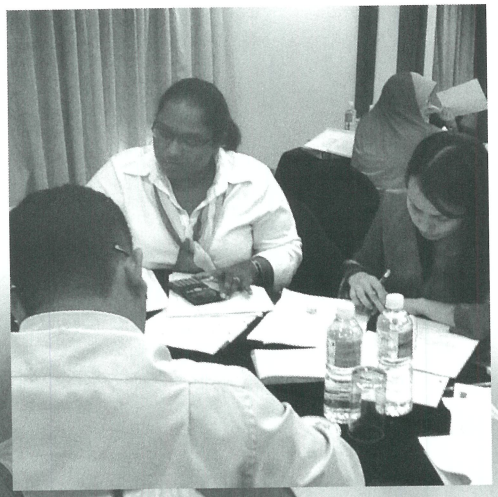
Establishment of effective communication line will create a **well informed management** that will be **sensitive** toward regulatory compliance hence will result in less chance of the industry be involved in unnecessary **enforcement actions**. **Corporate image** will not be tarnished and business growth affected by issues of environmental governance

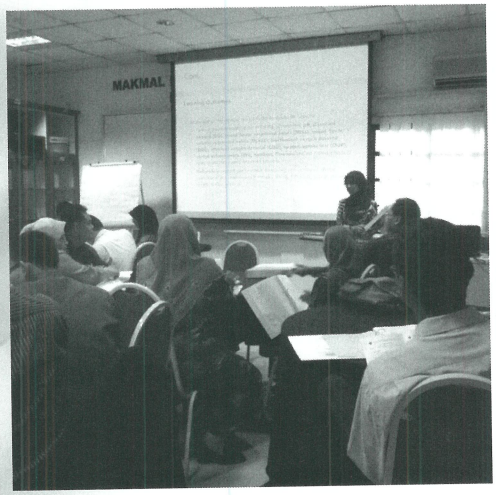
17.6 From the perspective of DOE officer/inspector

As a DOE officer/inspector you need to inspect the **tables / log sheets** maintained by the IETS team. The tables / log sheets and status reports will show whether the various PCPs have been operated in a sound manner in accordance with the principles explained in Chapter 12 and 13.

CHAPTER 18:

RECORD KEEPING, REPORTING AND COMMUNICATION





(ii) Thorough knowledge and understanding of the **fundamental concepts** of IETS processes and available **technologies** to treat different kinds of contaminants

(iii) Comprehensive knowledge and understanding of the important factors contributing to the **successful operation** of an IETS

(iv) Ability to interpret the IETS **performance monitoring data** and deduce whether an IETS has been operated in accordance with **sound engineering practices**

(v) Ability to provide **technical inputs** to IETS proposal assessments and non-compliance issues

(vi) Ability to perform comprehensive **technical inspection** of all components of IETS, whether they are biological or physical-chemical processes

(vii) Ability to communicate on IETS technical issues effectively to the management for **informed decision making**

You as a graduate of the CePIETSI program carry the mission in DOE that supports the efforts to:

(i) Cultivate the culture of **continuous learning**

(ii) Cultivate pride for possessing **technical knowledge and skills**

(iii) Groom and develop **subject matter experts** (SMEs) in IETS

(iv) Develop a core group of DOE subject matter experts who can provide IETS **consulting services**

(v) Change the enforcement mindset from a purely "compliance at the discharge point focus" to "**performance monitoring and in-process focus**"

(vi) Promote and fortify **self regulation** approach to the control of industrial water pollution

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CHAPTER 18:

RECORD KEEPING, REPORTING AND COMMUNICATION

18.1 Importance of record keeping practice

Record keeping plays an important role of the operation of an IETS. It is an integral part of **self regulatory approach** in pollution management and an essential element in self demonstration of compliance. Record keeping is not only now a **legal requirement** but it serves as an effective **management tool** in ensuring IETS is being operated, maintained and managed in an optimal fashion. Some elements effective record keeping and communication are discussed below.

18.2 Record keeping requirements

Maintaining IETS performance monitoring (PM) records is a legal requirement under regulation 27 of IER. Generally, **all unit operations and unit processes** are required to be monitored to ensure they are **optimally operated**, as a consequence the IETS will produce **compliant effluent** all the time. What PM records to keep and how to keep them are spelt out in **the Guidance Document on IETS Performance Monitoring (GD2)** issued by the Department of Environment. The **tables/log sheets** to be used by field technicians to record the **in-situ measurements and instrument readings** of PCP processes are shown in Appendix the GD2. Appendix K is for the recording of **corrective actions** taken to address **upset conditions**. The tables/log sheets can be modified to suit individual industry's situation provided that the basic elements in the original tables are maintained. The industries need to develop their own record keeping tables for PCP processes which are not listed in the GD2.

18.3 Maintaining records of IETS performance monitoring data

The data generated from performance monitoring activities are to be recorded in a suitable format which would facilitate easy understanding and retrievable. The minimum specifications on data format are stipulated in the **Guidance Document on Performance Monitoring of Industrial Effluent Treatment Systems** issued by the Department of Environment (Refer to the document for details). During **inspection duties** the DOE inspectors will ask for these data hence it is advisable that a separate file containing the data is kept at hand. The data can also be presented as illustrated in the data analysis session of this Resource Book. Soft copies of the data can be stored in a **database** while hard copies can be kept in the file for easy reference. Additionally, another important record to be maintained is the record on **"corrective actions"** taken to address upset conditions.

18.4 Data and report certification

All the forms on which the data are kept must be **signed** by the industry personnel taking the measurements and the forms are to be **countersigned** by the CePIETSO.

18.5 How long should you keep performance monitoring data?

Performance monitoring data should be kept for a **minimum period of three (3) years**.

18.6 Mainstreaming of IETS agenda

18.6.1 IETS day to day communication

On a day to day basis, a **formal communication channel** must be established where IETS issues are reported. This could be in the form of **shift/morning meetings**, or the like, where **impending problems** can be reported hence immediate corrective actions can be taken or addressed.

The management shall be kept informed of the status of compliance on a **scheduled basis**. Through a **formal set up,** abnormal situations can be promptly brought to the attention of the right personnel in the management to ensure "surprises" of non compliance does not occur.

18.6.2 IETS performance committee (PMC)

There should be a **formal and permanent committee** established within the industry to monitor the IETS performance on a **continuous basis**. This committee is commonly known as the performance monitoring committee (**PMC**). The members of PMC should comprise senior management personnel of the industry from various relevant departments. The establishment of this committee is also stipulated in GD2. The details of this committee must be described by the CePIETSO candidate in the **field training report**. Through this committee the results of the performance monitoring activities are presented, reviewed, and discussed. As an example monthly summary reports can be tabled at this meeting**. Trends** in IETS compliance can be reviewed by **senior management personnel** and potential IETS improvement plans discussed. Key industry personnel form relevant departments are directly involved in IETS issues and **jointly responsible** for ensuring regulatory compliance as such, the company's business plans can progress without hitches due to **noncompliance issues**.

The records of dates of PMC meetings must be maintained for inspection by the DOE inspectors. The conduct of PMC meetings is mandatory for CePIETSOs to maintain their registration with the DOE in the National Registry of Certified Environmental Professionals (NRCEP).

Continuous IETS compliance results from concerted efforts from all the relevant industry personnel, each playing their role and discharging their duties satisfactorily. Table 18.1 below summarizes **typical roles** to be played and actions to be taken by the industry personnel who may be represented in PMC towards ensuring continuous regulatory compliance.

Table 18.1: Different roles of key industry personnel in IETS operation

Industry personnel	Role and responsibility
General Manager/	Be informed of IETS status; decision on IETS improvement
Manager of Engineering Department	IETS hardware preventive and corrective maintenance; Energy saving measures in IETS operation
Manager of Production Department	Effluent minimization measures; discussion with PMC and others prior to change of chemicals that would affect IETS performance
Manager of Finance Department	Budget allocation for IETS improvement; IETS team training
IETS performance monitoring	IETS PM report review; review and recommendation
Committee (PMC)	of IETS improvement proposals; proposed changes in policy, raw materials, chemicals, etc that would affect IETS performance
CePIETSO	Daily IETS log review and verification; Periodic IETS PM report preparation; MDMR certification
Chemist; laboratory technician	Effluent analysis
Field technician	Effluent sampling; instrument reading; instrument calibration; in situ analysis; daily logs

18.6.3 Corporate social responsibility (CSR)

It is not enough just to comply with the minimum mandatory requirements stipulated by the regulatory agencies. The industries should strive to go **beyond compliance** and to initiate efforts that portray the image of good governance and demonstrate corporate social responsibility (CSR). CSR is now seen as a vital tool in promoting and improving the public image of an industry as well as an effective business strategy. CSR can take many different forms depending on several factors such as: the type of industry, the location of the industry, the nature of stakeholders (employees, suppliers, customers, the local communities), and the impact on the environment.

18.7 From the perspective of DOE officer/ inspector

As a DOE officer/inspector you understand that you need to **inspect the tables/log** sheets on their inspection rounds.to the industrial premises to ensure the required performance monitoring parameters are monitored and maintained withi the acceptable ranges.



CHAPTER 19:

THE CePIETSIs: THE AGENTS OF CHANGE







CHAPTER 19:

THE CePIETSIs: THE AGENTS OF CHANGE

19.1 Environmental sense makes business sense

There is definitely a compelling business case for environmental excellence. Studies have shown that organizations which have more well established **environmental sustainability programs** are more successful and achieve higher profits. Some of the attributes of **Environmental Excellence** are:

(i) The commitment from the organization is highly **visible**, rigorously pursued and cascades down **from the top to the bottom**

(ii) Environmental related activities are **infused** into day to day **organizational processes** including technical, management and decision making processes and are not viewed as separate initiatives

(iii) Staff **at all levels** are directly involved in either exploring innovative ideas to improve environmental practices or in implementing environmental improvement initiatives which have been rolled out

(iv) **Intangible benefits** such as increased regulatory compliance, improved community acceptance and enhanced corporate image are derived from environmental excellence activities

(v) **Tangible benefits** such as increased sales and profits, lower operational cost, lower income loss due to less down time are directly attributable to environmental excellence initiatives.

(Adapted from http://www.natcapsolutions.org/business)

Summing up it can be simply said that **'environmental excellence' leads to 'business excellence'.**

As a DOE officer you should spread the message that environmental protection and economic progress are **complementary** and not competing goals that drive us to a

sustainable society. You should preach the fundamental principle of a sustainable business practice which firmly believes that environmental excellence not only gives good corporate image but at the same time gives competitive **business advantage.**

19.2 The CePIETSI program and the new image of DOE officers

Through the CePIETSI program, DOE officers with a **new image** are produced. These officers possess the **knowledge (minds-on)** and **skills (hands-on)** in regulatory understanding, IETS technologies, operation and maintenance and IETS inspection. They are in a position to take up challenges to handle difficult IETS issues and provide technically defensible options to solve them. With regard to IETS aspects, the CePIETSIs are characterized by the following traits:

(i) High technical competence and confidence
(ii) Ability to explain and discuss
(iii) Technically influential
(iv) Facilitative
(v) Technically rational
(vi) Industry culture conscious
(vii) Promoter of self regulation
(viii) Outcome and results driven
(ix) Problem solving conscious

19.3 The CePIETSIs as the change agents

You as a graduate of the CePIETSI program have gone through 'minds on' and 'hands on' training and thus possess the following invaluable **assets:**

(i) Thorough knowledge and understanding of the **IER** and various aspects of **non-compliances**

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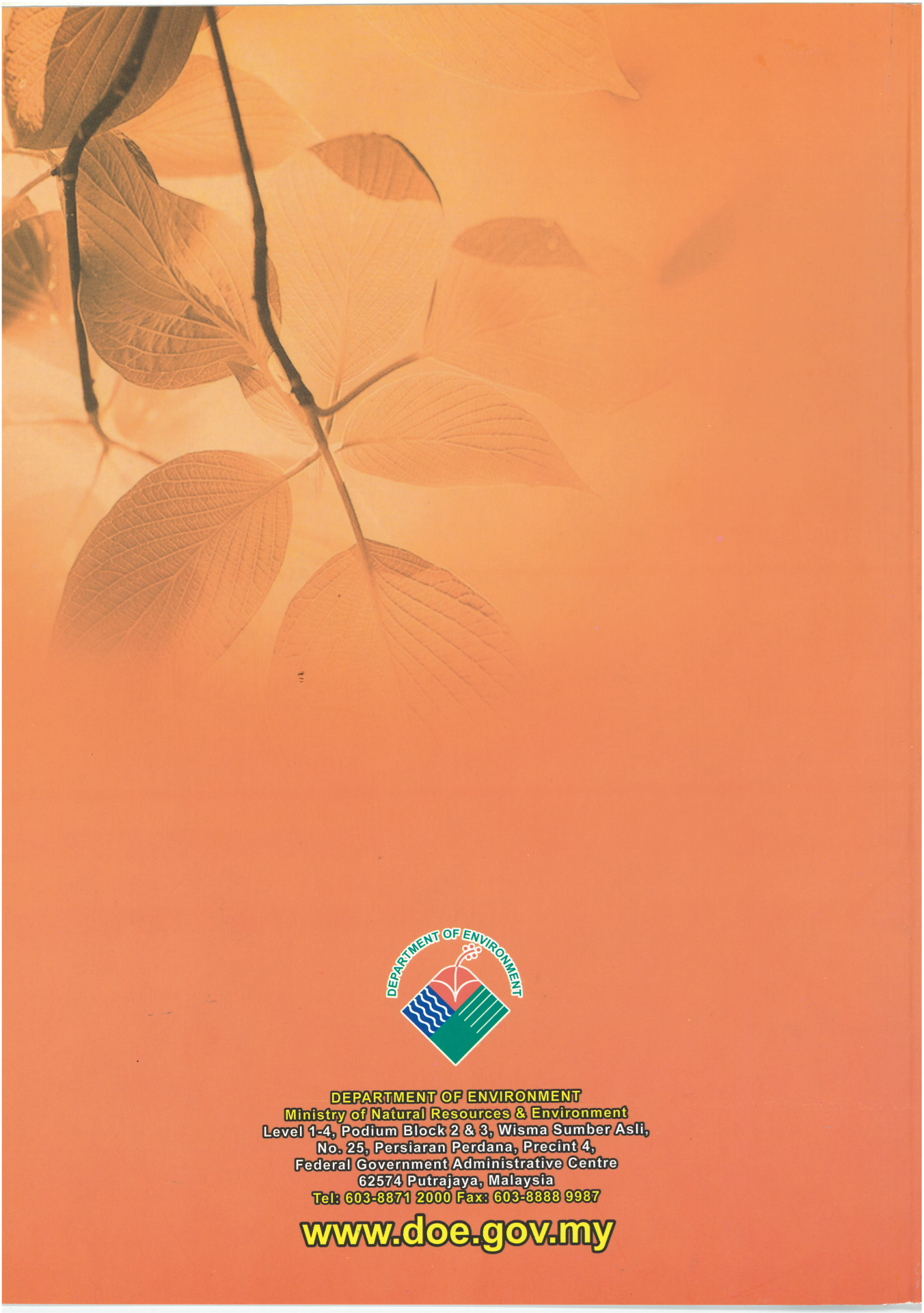

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