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DEPARTMENT OF ENVIRONMENT

GUIDANCE DOCUMENT ON THE DESIGN AND OPERATION OF INDUSTRIAL EFFLUENT TREATMENT SYSTEMS

Specified in Regulation 5, Environmental Quality (Industrial Effluent) Regulations 2009

DOE Headquarters
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FOR THE USE OF THE INDUSTRIES AND CONSULTANTS

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FOREWORD

The design procedure, considerations, requirements, criteria, standards and specifications of industrial effluent treatment system (IETS) described in this Guidance Document (to be referred to as "criteria") represent the minimum criteria that an owner of an industrial facility shall comply with. These criteria shall be met in order to comply with regulation 5 of the Industrial Effluent Regulations 2009 (to be referred to as IER). The owner shall take additional measures either in the form of providing redundancies, installation of additional equipment, providing higher safety factor, etc if these additional measures are deemed appropriate to further ensure compliance with the effluent discharge standards stipulated in the IER all the time. The Guidance Document will be reviewed and updated from time to time.

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March 2012

LIST OF ABBREVIATIONS

ADMI	American Dye Manufacturers Institute
A/S ratio	Air to solids ratio
BEM	Board of Engineers Malaysia
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DO	Dissolved oxygen
DOE	Department of Environment
EAAS	Extended aeration activated sludge
F/M ratio	Food to microorganism ratio
G	Velocity gradient
HLR	Hydraulic loading rate
HRT	Hydraulic retention time
IECS	Industrial effluent characterization study
IER	Industrial Effluent Regulations 2009
IETS	Industrial effluent treatment system
MBR	Membrane bioreactor
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
O&G	Oil and grease
OLR	Organic loading rate
O&M	Operation and maintenance
ORP	Oxidation reduction potential
OUR	Oxygen uptake rate
PID	Process and instrumentation diagram
PLC	Programmable logic controllers
RAS	Return activated sludge
SBR	Sequencing batch reactor
SCADA	Supervisory control and data acquisition
SI	Solids inventory
SLR	Solids loading rate
SOUR	Specific oxygen uptake rate
SS	Suspended solids
SSV	Settled sludge volume
SVI	Sludge volume index

TF	Trickling filter
TIN	Total inorganic nitrogen
TOC	Total organic carbon
UASB	Upflow anaerobic sludge blanket
UV	Superficial liquid upflow velocity
VOC	Volatile organic compound
WAS	Waste activated sludge
WET	Whole effluent toxicity
WOR	Weir overflow rate

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CHAPTER 1 : INTRODUCTION

The purpose of this Guidance Document is to stipulate:

- The minimum design criteria for common unit operations and unit processes to be complied with by the design engineers when undertaking an exercise in the design of an IETS at the design stage.
- The operating conditions to be maintained for various unit operations and unit processes by the IETS supervisors/operators at the operational stage.

The preparation of this document takes cognizance of the contributing factors that would result in a success story of industrial effluent treatment, namely an acceptable design of the IETS and later, its optimal operation. A well trained and an experienced engineer will ensure that the IETS is adequately designed and a competent operator will ensure that the IETS is optimally operated. As a consequence, the final result is a success story of regulatory compliance on a continuous basis and mitigation of adverse environmental impact.

1.1 Deviation from Design Criteria

Deviations from the design criteria stipulated in this Guidance Document which represent a more conservative design shall be accepted as a general principle. However, deviations which can be interpreted as a less conservative design shall be allowed only if documented evidence from actual operating IETSs or pilot plant studies can be substantiated to justify the use of lower design criteria without compromising the desired quality or outcome of the design exercise. The evidence shall be documented and submitted to the DOE in the notification package.

It is to be noted that for some IETS components, numerical design criteria have not been specified in this Guidance Document because of the nature of the design process and the design variables involved are application – specific and largely dependent on the desired quality of the product or outcome and management decision on the technology to be used. In these cases, wide flexibility is given to the design engineer in consultation with the client to decide on the design variables and operating conditions. However, all details used in the design including design criteria, design equations, calculations and operating conditions shall be documented and submitted to the DOE in the notification package.

1.2 Design of Unit Operations and Unit Processes not Discussed in Guidance Document

The types of unit operations and unit processes of IETS discussed in this Guidance Document are not exhaustive. Where unit operations and unit processes are not discussed, the design engineer shall design such IETS components according to established design criteria which shall be submitted to the DOE with the notification form.

1.3 Notification Requirement

Regulation 4 of the IER requires a new source or an altered source of effluent discharge or a case of an IETS upgrading /modification to notify the DOE via the use of the notification form specified in the Second Schedule. Details of the IETS including the design basis, design calculations, and detailed engineering drawings shall also be furnished along with the notification form as required under regulation 4(2) of the IER (see the Second Schedule).

1.4 Combined Treatment of Industrial Effluent and Sewage

In principle, the idea of treating an industrial effluent with sewage can be accepted as long as the characteristics of the effluent are compatible with those of the sewage. In practice, experience in developed countries has shown that, industrial effluents which contain biodegradable constituents have been successfully co-treated with sewage.

Since combined treatment is relatively new in Malaysia, the industry is strongly advised to consult the relevant authorities before embarking on a combined treatment project. Wherever relevant, consent or approvals from the authorities need to be obtained before the project is carried out. Additionally, a combined treatment project should be preceded by a thorough investigation of the compatibility of the effluent with sewage and the feasibility of combined treatment preferably, via a pilot plant study.

1.5 Explanation of Terms

The terms “shall” or “must” are used in the Guidance Document when it is required that the standard, procedure and criteria be used. Other terms such as “should” and “recommended” indicate desirable procedures, methods or criteria which should be considered.

CHAPTER 2: GENERAL CONSIDERATIONS AND PRINCIPLES

This chapter describes the general principles that the design engineers need to adhere to and the considerations needed to be taken into account when designing an IETS.

2.1 Design Engineers

Engineers who have undergone university training and obtained a degree in certain discipline are better equipped and hence are more appropriate to handle certain aspects of environmental problems. Nevertheless, it should be noted that engineers from one discipline, through additional training, such as post graduate courses and relevant on the job training, may develop sufficient working knowledge and expertise in other closely related disciplines. Professional ethics will dictate that one would not be willing to undertake an engineering assignment which is not within one's expertise. It is also to be noted that, courses in the design of wastewater treatment systems for treating industrial effluents or sewage are typically offered by the universities at the post graduate studies.

The design engineer who takes on a design assignment shall be a competent person as required under section 49A of the EQA. From the technical perspective of the IER, in performing an IETS design task, the following shall be adhered to.

2.1.1 Design of Physical Chemical Treatment Processes

The process and functional design of the physical chemical treatment processes shall be carried out by:

- A chemical engineer, or
- An environmental engineer, or
- A civil engineer who has taken courses in the design of physical chemical treatment processes at the undergraduate level or has undergone a postgraduate course in environmental engineering or water pollution control engineering, or
- An engineer in other relevant discipline who has undergone a postgraduate course in environmental engineering or water pollution control engineering.

2.1.2 Design of Biological Treatment Processes

The process and functional design of the biological treatment processes shall be carried out by:

- An environmental engineer, or
- A chemical or civil engineer who has taken courses in the design of biological treatment processes at the undergraduate level or has undergone

a postgraduate course in environmental engineering or water pollution control engineering, or

- An engineer in other relevant discipline who has undergone a post graduate course in environmental engineering or water pollution control engineering.

Apart from the requirement on university training specified above, the design engineer shall have sufficient design experience which has been obtained under the supervision of senior engineers.

2.1.3 Design of Mechanical, Electrical, and Electronic Components

The design of mechanical, electrical, or electronics components as well as the structural design shall be carried out by relevant engineers in conformance to the applicable legislations which are currently in force.

2.1.4 Professional Engineers

All the engineers involved in the design assignment shall be professional engineers who maintain current registration with the Board of Engineers Malaysia (BEM).

2.2 Effluent Flowrate

2.2.1 Effluent Flowrate Estimation

Determination of the flowrate of industrial effluent is a fundamental step in the design of effluent collection and treatment systems. Reliable data on existing and projected effluent flows must be available if the IETS is to be designed properly. For existing industrial manufacturing industries effluent flowrate estimate shall be developed from water consumption record or from the analysis of flowrate data or from actual measurements such as those conducted in industrial effluent characterization studies (IECSs) (Refer to the Guidance Document on Industrial Effluent Characterization Studies published by the DOE). For new manufacturing industries, estimates shall be made using data from existing industries operating elsewhere utilizing similar manufacturing processes or from published data.

2.2.2 Flowrate for Design

For the design of IETS, it is recommended that the peak flow (i.e. the maximum daily flow, Q_{peak}) is used. The maximum daily flow is important particularly in the design of facilities involving detention time such as equalization basins and the design of transmission elements such as conduits and distributor mechanisms.

Q_{peak} is computed from the relationship:

$$Q_{peak} = Q_{average} \times \text{peaking factor} \quad \ldots\ldots\ldots\ldots(2.1)$$

An appropriate peaking factor must be determined by the design engineer based on the operational characteristics of the manufacturing processes employed in the industry.

2.3 Significant Pollution Parameters

Based on literature data or experience with similar industries, or information from an IECS conducted previously or raw materials and manufacturing processes employed, the engineer shall identify the significant pollution parameters in the effluent streams. Table 2.1 below gives a guide on significant pollution parameters for some common industry categories/types. Table 2.2 summarizes industrial sources of metal dischargers.

Table 2.1: Significant 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, Ammoniacal nitrogen,
Fertilizer (Phosphate)	T, pH, COD, SS, Ammoniacal nitrogen, Fluoride
Pulp and Paper	T, pH, BOD_5, COD, SS, Sulfides,
Petroleum Refining	T, pH, COD, SS, BOD5, O&G, Phenolic compounds
Steel Industry	T, pH, COD, SS, Chromium (trivalent), Iron, Cadmium, Copper, Fluoride, O&G
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,
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

Table 2.1 continued

Pesticides	pH, COD, Mercury, Fluoride
Printing	COD, SS, Lead, Color
Industrial Chemicals	pH, BOD_5, COD, SS Phenolic Compounds, Cyanide, Ammoniacal Nitrogen, Cadmium, Lead, Chromium, Mercury, Nickel, Zinc, Arsenic
Oil & Gas Exploration and Production	T, pH, BOD_5, COD, SS, O&G, Chloride, Phenolic Compounds, Boron, Fluoride, Formaldehyde, Sulfides, Ammonia
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, Fluoride, 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
Electronics	T, pH, BOD_5, COD, SS, O&G, Fluoride, Ammoniacal Nitrogen, Copper, Nickel, Chromium, Tin, Lead, Cyanide, Sulfates
Vegetable Oil Mills	T, pH, BOD_5, COD, SS, O&G
Plastic Materials and Products	SS, endocline disruptors
Solar Panel Industry	pH, BOD, COD, SS, Fluorides
Wood Products	pH, SS, COD, Phenolic compounds
Pharmaceutical	T, pH, BOD_5, COD, SS

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

2.4 Mass Balance

A mass balance is a set of calculations used to account for the mass flows of various contaminants across the different unit processes and unit operations that make up the entire IETS. For an existing industry intending to upgrade its IETS or in the process of identifying solutions to its effluent non-compliance problem, an IECS shall be performed. An integral part of the study is the development of a mass balance model to track major pollutants such as BOD, COD, SS and metals in the liquid and solid streams in the IETS. Mass balances shall be developed to assess equipment performance based on existing data or to project future loading when a manufacturing facility is intending to adopt manufacturing process changes or to increase production capacity. To represent steady state plant operations, annual or monthly data, wherever relevant, shall be used for the development of mass balance. Mass balance calculations are required to be performed only for an IETS involving the removal of metals in new or existing industries.

Table 2.2 : Typical industrial sources of metals in effluents

Metal	Industrial Source
Arsenic	Metallurgical industry; glassware and ceramic production; tannery operation; dyestuff manufacture; pesticide manufacture; petroleum refining; some organic and inorganic chemicals manufacture; rare earth industry.
Barium	Paint and pigment industry; metallurgical industry, glass manufacture; ceramics industry; dye manufacture; rubber vulcanization process; explosives industry.
Cadmium	Metallurgical alloying process; ceramics industry; electroplating; photographic industry; pigment works; textile printing; chemical industry.
Copper	Metal pickling baths and plating baths; chemicals manufacturing employing copper salts or a copper catalyst; printed wire board industry; solar cell manufacture.
Fluorides (non metal)	Glass manufacture; electroplating industry; steel and aluminum industry; pesticides manufacture; fertilizer manufacture; photographic industry; silicon wafer industry; cathode ray tubes industry; steel industry; solar panel manufacture.
Iron	Mining operation; ore milling, chemical industries; dye manufacture; metal processing; textile industry; petroleum refining.
Lead	Lead acid battery manufacture; printed wire board industry.
Manganese	Steel alloy industry; dry cell battery manufacture; glass and ceramics industry; paint and varnish manufacture; ink and dye works.
Mercury	Chlor-alkali industry; electrical and electronics industry; explosives manufacture; photographic industry; chemical and petrochemical industry; laboratory effluents; incinerator; battery manufacture; bulb/lamp manufacture.
Nickel	Metal processing industry; steel foundries; motor vehicle industry; air craft industry; printing industry; chemical industry; nickel electroplating industry; printed wire board industry.
Selenium	Flyash pond from fossil fuel combustion; sulfide ore processing; coal-fired power plant cooling water discharge.

Table 2.2 continued

Silver	Porcelain works; photographic industry; electroplating industry; ink manufacture; printed wire board industry.
Zinc	Steelworks; rayon yarn and fiber manufacture; rubber glove industry; wood-pulp production; recirculating cooling water employing cathodic treatment.
Boron	Ceramic industry; fiberglass insulation industry; borosilicate glass manufacture; detergent industry; fertilizer manufacture; metallurgy industry.

2.5 Preliminary or Primary Treatment

Effective removal of grit, debris, excessive oil and grease, metals and other contaminants that could affect the biological process shall be accomplished prior to subjecting the effluent to the biological treatment processes.

2.6 Segregation of Effluent Streams

Separate drainage system for storm water shall be provided with no possibility for the storm water to be mixed with process effluent streams. Preferably, the effluent streams are conveyed through a piping system which shall be properly colored and labeled.

Incompatible effluent streams, for example cyanide – bearing effluent stream must be segregated from acidic effluent streams to prevent the evolution of toxic hydrogen cyanide gas. Similarly, highly concentrated batch dumps must be treated separately and must not be mixed with the rest of the effluent streams.

2.7 Redundancies

The principle of redundancy to be adhered to in the design process is that the design of major components of the IETS, shall provide sufficient units and capacity to ensure that the IETS is fully operational even during maintenance period and peak flows. Provision of "off specification" storage tanks to divert non-compliant effluent for temporary storage is a recommended design practice to confirm to the redundancy principle. If this redundancy principle has not been complied with in the design, the manufacturing activity generating the effluent streams needs to be shut down whenever there is an equipment malfunction or the IETS is scheduled for maintenance. Essential accessory equipment such as instruments/sensors for perfomance monitoring shall also be provided with redundancies.

2.8 Batch Discharges

If an IETS is designed to discharge its final effluent on a batch basis, any discharge of effluent shall be preceded by sampling of the effluent and analysis of the relevant parameters which can be made in a short time frame. Such parameters include COD and metals which are amenable to rapid measurement using portable equipment. Compliance with the discharge standards shall be assured before the discharge is allowed. A record of the discharge details including the time, the discharge quality, the competent person authorizing the discharge etc. shall be maintained by the industry for the inspection by the DOE officers.

2.9 Submittal of Design Calculations

Detailed engineering calculations shall be submitted to justify the basis of design for all the unit processes and unit operations of the entire IETS. The calculations shall show the basis for sizing the aeration tanks, aeration equipment, clarifiers, return activated sludge (RAS) equipment, waste activated sludge (WAS) equipment, corrugated plate interceptor, dissolved air flotation (DAF) unit, precipitation tank, coagulation tank, flocculation tank, ion-exchange column, adsorption column, chemical dosing system, nutrient requirements, media filter, equipment involving membrane processes, transfer pumps, metering pumps, equalization tanks, screens, sludge handling and dewatering facilities, etc. The quantities of chemicals to be used shall also be computed. All assumptions made shall be clearly stated.

2.10 Flow Charts and Process and Instrumentation Diagram (PID)

The following flowcharts and diagrams shall be prepared and submitted to the DOE in the notification package.

- Flow chart of the manufacturing process indicating the points of generation of effluent streams
- Flow chart of the IETS
- Process and instrumentation diagram (PID) of the IETS

2.11 All Effluent Streams Must Undergo Treatment

The design engineer shall identify all effluent streams both directly attributable to the various manufacturing processes and those generated via other activities occurring within the industrial premise. The latter sources include contaminated stormwater from raw materials storage yard, shop floor cleaning, spills, valve leaks, and boiler blow down water which has been pretreated with copper-based biocides, water scrubber effluents, non-contact cooling water as well as general storm water. Effluent streams generated from manufacturing processes and from activities/events which generate contaminated discharges (e.g. contaminated stormwater, valve leaks, biocide-pretreated boiler blowdowns) shall be collected and channeled to the IETS for treatment. Additionally, best industry practices for managing other sources of effluents generated on the premise such as non-contact cooling water and storm water shall be identified and considered in the design of the industrial premise. Discharge of treated effluent from the premise shall take place only through the designated discharge point immediately downstream of the last unit operation or unit process of the IETS.

An effluent stream can be considered for separate treatment if the practice conforms to the industry's best practice for that category of industry or type of effluent. In such a case, the final effluent from the separate treatment unit can be discharged separately through another discharge point. All discharge points shall conform to the requirements set out in regulation 17 of the IER.

2.12 Compliance with Discharge Standards

The specifications stipulated in this Guidance Document represent the minimum requirements and criteria to be complied in the design and operation of an IETS. However, the overall responsibility still rests with the owner of the industry to ensure the final effluent quality meets the applicable discharge standards. The design engineers and the owner shall take additional measures deemed appropriate to ensure discharge compliance is met at all time. The discharge standards stipulated in the Fifth, Seventh and Eighth Schedules of the IER are reproduced in Table 2.3, 2.4, and 2.5 for ease of reference.

2.13 Maintenance of IETS and its components

Provisions must be made in the design to easily remove major components to permit maintenance and repair without interrupting the operation of the IETS. For example, aeration diffusers must be easily removed for service or replacement without dewatering the aeration tank and without inhibiting the operation of the other aeration equipment.

2.14 Operation and Maintenance Manual

A complete and comprehensive IETS operation and maintenance manual shall be prepared and made available to the supervisor/operator of the IETS.

2.15 On Site Lab Facilities

To ensure optimal performance of the IETS, constant monitoring of the processes occurring in the IETS is essential. This warrants the establishment of a laboratory equipped with basic facilities within the industry premise to enable the IETS personnel to conduct routine performance monitoring activities such as sampling, sample preservation, equipment calibration, sample analysis, etc. Performance monitoring measurement of flow, pH, oxidation reduction potential (ORP), dissolved oxygen (DO), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), sludge volume index (SVI), specific oxygen uptake rate (SOUR) and jar tests, etc. is part and parcel of IETS operation which can be made by using in-situ rapid testing methods or portable instruments without having to wait for "very accurate results" from the accredited laboratory. The measurement of these parameters which is done on a routine basis is facilitated by having a laboratory provided in close proximity to the IETS site. The laboratory shall be equipped with suitable laboratory apparatus for routine testing and performance monitoring of the IETS. Appropriate adjustments to the IETS operation can immediately be made based on the results of this routine monitoring.

Table 2.3: Fifth Schedule to the Industrial Effluents Regulations 2009

[Paragraph 11]

ACCEPTABLE CONDITIONS FOR DISCHARGE OF INDUSTRIAL EFFLUENT OR MIXED EFFLUENT OF STANDARDS A AND B

	Parameter	Unit	Standard A	Standard B
	(1)	(2)	(3)	(4)
(i)	Temperature	°C	40	40
(ii)	pH Value	–	6.0-9.0	5.5-9.0
(iii)	BOD_5 at 20°C	mg/L	20	50
(iv)	Suspended Solids	mg/L	50	100
(v)	Mercury	mg/L	0.005	0.05
(vi)	Cadmium	mg/L	0.01	0.02
(vii)	Chromium, Hexavalent	mg/L	0.05	0.05
(viii)	Chromium, Trivalent	mg/L	0.20	1.0
(ix)	Arsenic	mg/L	0.05	0.10
(x)	Cyanide	mg/L	0.05	0.10
(xi)	Lead	mg/L	0.10	0.5
(xii)	Copper	mg/L	0.20	1.0
(xiii)	Manganese	mg/L	0.20	1.0
(xiv)	Nickel	mg/L	0.20	1.0
(xv)	Tin	mg/L	0.20	1.0
(xvi)	Zinc	mg/L	2.0	2.0
(xvii)	Boron	mg/L	1.0	4.0
(xviii)	Iron (Fe)	mg/L	1.0	5.0
(xix)	Silver	mg/L	0.1	1.0
(xx)	Aluminum	mg/L	10	15
(xxi)	Selenium	mg/L	0.02	0.5
(xxii)	Barium	mg/L	1.0	2.0
(xxiii)	Fluoride	mg/L	2.0	5.0

Table 2.3 continued

(xxiv)	Formaldehyde	mg/L	1.0	2.0
(xxv)	Phenol	mg/L	0.001	1.0
(xxvi)	Free Chlorine	mg/L	1.0	2.0
(xxvii)	Sulphide	mg/L	0.50	0.50
(xxviii)	Oil and Grease	mg/L	1.0	10.0
(xxix)	Ammoniacal Nitrogen	mg/L	10	20.0
(xxx)	Color	ADMI*	100	200

*ADMI- American Dye Manufacturers Institute

Table 2.4: Seventh Schedule to the Industrial Effluents Regulations 2009

(Regulation 12)

ACCEPTABLE CONDITIONS FOR DISCHARGE OF INDUSTRIAL EFFLUENT CONTAINING CHEMICAL OXYGEN DEMAND (COD) FOR SPECIFIC TRADE OR INDUSTRY SECTOR

	(1)	(2)	(3)	(4)
	Trade/Industry	**Unit**	**Standard**	**Standard**
			A	B
(a)	Pulp and paper industry			
	(i) pulp mill	mg/L	80	350
	(ii) paper mill (recycled)	mg/L	80	250
	(iii) pulp and paper mill	mg/L	80	300
(b)	Textile industry	mg/L	80	250
(c)	Fermentation and distillery industry			
	(i) Before 30.6.2009	mg/L	500	500
	(ii) 1.7.2009 and thereafter	mg/L	400	400
(d)	Other industries	mg/L	80	200

Table 2.5: Eighth Schedule to the Industrial Effluents Regulations 2009

(Regulation 13)

ACCEPTABLE CONDITIONS FOR DISCHARGE OF MIXED EFFLUENT CONTAINING CHEMICAL OXYGEN DEMAND (COD)

(1)	(2)	(3)
Unit	**Standard A**	**Standard B**
mg/L	80	200

2.16 Proper Operation of IETS

At the operational stage, the IETS shall be properly operated where the operational parameters as determined and specified at the design stage are maintained within the acceptable ranges.

2.17 Requirement for IETS Competent Person

In accordance with regulation 10 of the IER, the operation of the IETS shall be supervised by a competent person. The requirement is also stipulated in section 49A of the EQA (Amendment 2012)

2.18 Report of Studies

Report of any studies (such as industrial effluent characterization studies or effluent treatability studies, jar tests) conducted in connection with the IETS design exercise shall be submitted together with the notification package.

CHAPTER 3: DESIGN OF BIOLOGICAL TREATMENT PROCESSES

This chapter describes the general design considerations that shall be taken into account and the criteria followed when designing any biological treatment system.

3.1 Process Selection

Dissolved organic matter found in the industrial effluents is removed by employing biological treatment processes. These include suspended growth systems such as the activated sludge processes and attached growth systems (or fixed film systems) such as the trickling filters or rotating biological contactors. In the Malaysian setting, with the exception of a few installations, attached growth processes are seldom used to treat industrial effluents. Biological treatment processes are also categorized as aerobic process, anaerobic process or anoxic process. Most biological treatment processes employed for the treatment of industrial effluents in Malaysia are typically of the aerobic process type. However, with the requirement on nutrients control in the IER, anoxic process may become more prevalent in Malaysia in the future.

Based on effluent characteristics and practical experience with similar industries, the engineer shall justify the choice of the biological treatment process for the industrial effluent to produce final effluent that would comply with the applicable discharge standards. The design of the related unit processes such as clarifiers and sludge processing, shall also comply with the requirements stipulated in the other chapters of this Guidance Document. Calculations and documentation shall be submitted to the DOE to justify the basis of design of the entire IETS as required under regulation 4(2) of the IER (see the Second Schedule).

3.2 Equalization Basins/ Tanks

Equalization basins serve the objective of minimizing the fluctuation in the flow and concentration of the influent. Whenever necessary, equalization basins shall be provided to serve any of the following purposes:

(i) Elimination of organic shock load
(ii) Stabilization of pH, hence minimizing chemical treatment
(iii) Minimization of flow surges to physical chemical treatment systems
(iv) Prevention of high concentration of toxic materials entering the biological systems.

3.2.1 Design of Equalization Basins/ Tanks

Equalization shall be provided when there is considerable fluctuation in flow and pollutant concentrations. The size of the equalization basin shall be adequate to absorb pollutant fluctuations and dampen concentrated batches. Adequate mixing shall be provided through the use mechanical mixers or other methods of mixing.

For an existing industry, if an equalization basin is to be provided, the actual size of the basin shall be determined by performing a series of calculations involving time versus flowrate data. For a new industry to be established, the size of the equalization basin shall be determined on the basis of acceptable detention time, ranging from 2 to 3 hours or more depending on the industry's particular needs. The volume (V) of the basin is computed from the general relationship.

$$V = Q_{peak} \times HRT \text{ .... } (3.1)$$

where:

Q_{peak} = maximum daily flow, m^3/h.
V = volume of equalization basin, m^3
HRT = hydraulic retention time, h

3.3 Activated Sludge Process and its Variants

The activated sludge process and its various modifications have been widely employed successfully to treat industrial effluents from a wide range of industrial manufacturing facilities for the removal of biodegradable organics. The choice of the process most applicable to a particular situation will be dictated by several factors such as the effluent flowrate, effluent characteristics, degree and consistency of treatment required and stipulated discharged standards imposed by the regulatory agency. All designs shall incorporate for flexibility of different modes of operation of the IETS to cater for the variability in manufacturing operation of the industry.

There are a number of variants of the activated sludge system which can be classified according to several characteristics such as sludge age (θ_c) or food to microorganism (F/M) ratio or flow. Based on the sludge age, comparing the conventional activated sludge systems with the extended aeration systems, the latter are operated at low organic loadings (i.e. low F/M ratios and high sludge ages) resulting in a low sludge production and a high-quality effluent. From the flow standpoint, the activated sludge system can be a continuous or a batch system.

In Malaysia, there are three major types of activated sludge systems which are commonly used to treat industrial effluents. These are: conventional activated sludge (CAS) system, extended aeration activated sludge system (EAAS) and sequencing batch reactors (SBRs). Another version of the activated sludge process which has been adopted by several industries is the membrane bioreactor (MBR). Upflow anaerobic sludge blanket (UASB) is an anaerobic process which is gaining popularity for treating high strength organic effluents. All of the above processes are briefly described below:

- CAS system is characterized by introduction of influent stream and return activated sludge at one end of the aeration tank, a plug-flow aeration tank and different types of aeration system.
- EAAS system is characterized by a low F/M ratio, long θ_c and long aeration tank HRT.
- SBR is a fill-and-draw, non steady state activated sludge process in which one or more reactor basins are filled with effluent during a discrete time period and then operated in a batch treatment mode. SBR accomplishes equalization, aeration and clarification in a timed sequence.
- MBR is an activated sludge system where the secondary clarifier is replaced by a membrane filtration unit. It is typified by long θ_c and high MLSS.

Other variants of activated sludge process are: step aeration, tapered aeration, contact stabilization, high-rate aeration and high purity oxygen. These are not common in Malaysia, hence will not be discussed in this Guidance Document.

3.4 Conventional Activated Sludge System

3.4.1 Design Criteria for Conventional Activated Sludge System

The design engineer shall use the design criteria summarized in Table 3.1. when designing a conventional activated sludge (CAS) system for treating industrial effluents.

All design parameters shall be checked to determine if they fall within the typical range for the selected F/M ratio or sludge age and the aeration tank volume. Diurnal load variation and peak loading shall be considered when checking critical parameters.

3.4.2 Design Methodology for Conventional Activated Sludge System

The volume of the aeration tank shall be determined by using the F/M ratio or the sludge age approach based on the kinetic relationships.

Table 3.1: Summary of typical design criteria for conventional activated sludge systems

Design variable	Unit	Design Range
Minimum number of aeration tank	-	2
F/M ratio	kg BOD/(kg MLVSS.d)	0.25 to 0.50

Table 3.1 continued

HRT	h	6 to 16 (for ammonia removal) 12 to 12 16 (for total nitrogen removal)
O_2 requirement	kg O_2/kg BOD_5	0.5 to 1.1
MLSS	mg/L	1500 to 3000
DO in aeration tank	mg/L	1.0 to 2.0 2.0 to 3.0 (with nitrification)
Yield coefficient, Y	kg VSS /kg BOD_5	0.6 to 0.8
Decay coefficient, k_d	d^{-1}	0.03 to 0.15
Sludge age, θ_c	d	5 to 10
Organic loading	kg BOD_5 /(m^3.d)	0.3 to 0.6

Note:
The values of kinetic coefficients and appropriate design variables depend on the characteristics of the effluent, hence for existing industries must be determined for each effluent from bench or pilot plant studies. Values given here are typical for sewage.

The formula for calculating the aeration tank volume is commonly written as:

$$V = \frac{Y\theta_c Q(S_o - S)}{X_v(1 + k_d f_b \theta_c)} \qquad ......(3.2)$$

where

- V = aeration tank volume, m^3
- Y = yield coefficient, kg VSS produced/kg BOD_5 removed
- θ_c = sludge age, d
- Q = influent flowrate, m^3/d
- S_o = total BOD_5 of aeration tank influent, mg/L
- S = soluble BOD_5 of aeration tank effluent, mg/L
- X_v = MLVSS concentration, mg/L
- k_d = decay coefficient, d^{-1}
- f_b = biodegradable fraction of VSS immediately after generation in the system ($\theta_c = 0$)

A smaller aeration tank volume is obtained if f_b is not taken into account (i.e. $f_b = 0$).

Apart from the aeration tank volume, the design engineer shall compute other parameters which include F/M ratio, return sludge flow, excess sludge flow and hydraulic retention time. The relevant formulas for computing the above parameters are given below.

Calculation of return sludge ratio (R):

$$R = \frac{Q_r}{Q} \qquad \text{....... (3.3)}$$

where:

R = return sludge ratio
Q_r = return flow, m^3/d
Q = return flow, m^3/d

Calculation of return sludge suspended solids concentration (X_r):

$$X_r = X\frac{(R+1)}{Q} \qquad \text{....... (3.4)}$$

where:

X_r = SS in return sludge, mg/L
X = SS in aeration tank, mg/L

Calculation of hydraulic retention time (HRT or θ):

$$HRT\ (\text{or}\ \theta) = \frac{V}{Q} \qquad \text{....... (3.5)}$$

where:

HRT (or θ) = hydraulic retention time, d or h
V = aeration tank volume, m^3
Q = effluent flowrate, m^3/d

Calculation of food to microorganism (F/M) ratio:

$$F/M = \frac{QS_o}{VX_v} \qquad \text{............(3.6)}$$

where:

F/M = food to microorganism ratio, d^{-1}
Q = effluent flowrate, m^3/d
S_o = effluent BOD, mg/L
V = aeration tank volume, m^3
X_v = Mixed liquor volatile suspended solids concentration, mg/L

Calculation of sludge wasting rate (Q_{was}):
If sludge wasting is carried out directly from the aeration tank,

$$Q_{was} = \frac{V}{\theta_c} \qquad \text{.......(3.7)}$$

where:

Q_{was} = sludge wasting rate, d^{-1}
V = aeration tank volume, m^3
θ_c = sludge age, d

If sludge wasting is performed from the recycle line,

$$Q_{was} = \frac{VX}{\theta_c X_r} \qquad \text{......(3.8)}$$

where:

Q_{was} = sludge wasting rate, d^{-1}
V = aeration tank volume, m^3
X = SS in aeration tank, mg/L
θ_c = sludge age, d
X_r = SS in return sludge, mg/L

The other relevant formulae for designing the associated components of the activated sludge system are described in other sections of the Guidance Document. Table 3.3 gives a guide on the calculation sequence in a typical design exercise.

3.5 Extended Aeration Activated Sludge System

3.5.1 Design Criteria for Extended Aeration Activated Sludge System

The design criteria summarized in Table 3.2. shall be used for designing an extended aeration activated sludge (EAAS) system for treating industrial effluents.

Table 3.2: Summary of typical design criteria for extended aeration activated sludge systems

Design variable	Unit	Design Range
Minimum number of aeration tank	-	2
F/M ratio	kg BOD/(kg MLVSS.d)	0.05 to 0.15
HRT	h	18 to 36
O_2 requirement	kg O_2/kg BOD_5	1.2 to 1.6
MLSS	mg/L	3500 to 6000
DO in aeration tank	mg/L	1.0 to 2.0 2.0 to 3.0 (with nitrification)
Yield coefficient, Y*	kg VSS /kg BOD_5	0.3 to 0.5
Decay coefficient, k_d*	d^{-1}	0.03 to 0.15
Sludge age, θ_c	d	15 to 35
Organic loading	kg BOD_5 /(m^3.d)	0.1 to 0.4

3.5.2 Design Methodology for the Extended Aeration Activated Sludge System

The design of the aeration tank and other components of the EAAS system follows the same procedure as the case of the CAS system. To assist the design engineers in the design exercise, typical steps involved in the design of a CAS system or an EAAS system are summarized in Table 3.3.

Table 3.3: Sequence of calculation for the design of conventional or extended aeration activated sludge systems

Item Number	Item	Common Designation	Unit	Range/ Remarks	Equation
1.	**Design variable**				
1.1	Q	Influent flowrate	m^3/d	Design value	-
1.2	S_o	Influent BOD_5	mg/L	Design value (Total BOD_5)	-
1.3	S	Effluent BOD_5	mg/L	Soluble BOD; effluent BOD desired	-
1.4	θ_c	Sludge age	d	Depends on system; 5-10 d for CAS and 15-35 d for EAAS	-
1.5	X_v	Mixed liquor volatile suspended solids (MLVSS)	mg/L	Depends on system; 1200-2400 mg/L for CAS and 2800- 4800 mg/L for EAAS	-
2.	**Coefficients**				**-**
2.1	Y	Yield coefficient	kg VSS / kg BOD_5	Depends on system; 0.6 to 0.8 for CAS and 0.3 to 0.5 for EAAS	-
2.2	k_d	Decay coefficient	d^{-1}	0.03 to 0.15; normally assumed for design purpose	-
2.3	f_b'	Biodegradable fraction of VSS immediately after generation in the system ($\theta_c = 0$)	-	Typical value = 0.8, normally assumed for design purpose	-
2.4	f_b	Biodegradable fraction of VSS subject to a sludge age θ_c	-	Depends on system	$f_b = \frac{f_b'}{[1 + (1-f_b')k_d\theta_c]}$

Table 3.3 continued

3.	Computed Values				
3.1	V	Aeration tank volume	m^3	-	$V = \dfrac{Y \theta_c Q (S_o - S)}{X_v(1 + k_d f_b \theta_c)}$
3.2	HRT	Hydraulic retention time	h	Depends on system; 6-8 h for CAS and 18-36 for EAAS	HRT = V/Q
3.3	F/M ratio	Food to microorganism ratio	kg BOD/(kg MLVSS.d)	Depends on system; 0.25-0.5 for CAS and 0.05-0.15 for EAAS	$Q S_0/VX_v$
3.4	R	Return sludge ratio	unitless	-	$R = Q/Q_r$
3.5	Q_{was}	Wasting rate	m^3/d	Depend on where wasting is done	Q_{was}/θ_c or $Q_{was} = VX/\theta_c X_r$

3.6 Membrane Bioreactor Systems

A membrane bioreactor (MBR) system combines an activated sludge process with a membrane filtration unit; the latter replaces the secondary clarifier in a typical activated sludge system. The design engineer shall design the activated sludge process according to the design procedure described earlier in sections 3.4 and 3.5. In the design of the membrane filtration unit, the design engineer shall take into consideration, incorporate, or specify the following:

- Type of design of the membrane unit-submerged or external
- Membrane configuration-hollow fiber or plate and frame
- Membrane type based on pore size-ultrafilter or microfilter
- Coarse screen installation
- Scouring air facilities; scour air flowrate (m^3/min)
- Vacuum air pressure (bar)
- Membrane unit operation and maintenance (frequency and specifications on physical inspection, chemical treatment, etc.)
- Design criteria and performance monitoring set points/ranges

3.7 Sequencing Batch Reactor Systems

Sequencing batch reactors (SBRs) are principally fill-and-draw reactors that remove dissolved organic contaminants and nutrients from industrial effluents. SBRs are an attractive option for small and medium effluent flows of 19,000 m^3/d or less. One of the advantages of the SBR is that it eliminates the need for the clarifier because equalization, reaction and clarification all happen in one tank via a time controlled sequence, hence affords substantial savings in capital cost. SBRs are typically designed and operated on an extended aeration mode.

3.7.1 Design Criteria for Sequencing Batch Reactor Systems

SBR systems that receive effluent intermittently shall be designed using the same basic design parameters of the continuous flow activated sludge system. The design engineers shall use the design criteria summarized in Table 3.4 for designing SBR systems to treat industrial effluents. Other criteria such as oxygen requirements, oxygen level to be maintained, etc shall comply with the criteria set for the continuous flow activated sludge system.

Table 3.4: Summary of typical design criteria for sequencing batch reactors (Source: AquaSBR, 1995)

Design variable	Unit	Design range for operation in conventional mode	Design range for operation in extended aeration mode
Minimum number of tanks	-	2	2
F/M ratio	kg BOD_5/ (kg MLVSS.d)	0.15 to 0.40	0.05 to 0.10
MLVSS	mg/L	2000 to 4000	4000 to 6000
Operational cycle	h	4 to 24	5 to 48
HRT	h	depends on effluent characteristics, typically, 6 to 8	depends on effluent characteristics, typically, 15 to 40
Freeboard depth***	mm	460	460

3.7.2 Design Methodology for Sequencing Batch Reactor Systems

In practice, several methods are commonly used for the design of SBR systems. The majority of the methods are based on the sludge volume index (SVI) approach (Eckenfelder, Ford and Englande, 2008; Metcalf and Eddy, 2003; Orhon and Artran, 1994) while von Sparling (1998) adopted a different approach where a sequence of calculations is proposed to determine the reactor volume and duration of the operational cycle. Both approaches are acceptable as long as the chosen method is properly followed and clearly referenced in the design document submitted to the DOE with the notification package. The design calculations may involve the estimation of the concentration and volume of the settled sludge, duration of the operational cycle, volume of the reactor, number of basins, decant volume, and detention time. Then, the aeration equipment, decanter and associated piping shall be computed.

In SBR design, special conditions shall be given to the following:

- The design shall include at least two parallel SBRs to enable operation to continue when one unit is taken out of service for maintenance.
- A pre-aeration, flow equalization basin shall be provided for when the SBR is in the settle and/or draw phases. If multiple SBR basins are provided a pre-aeration basin will not be needed if each SBR basin is capable of handling all the influent peak flow while another basin is in the settle and/or draw phase.
- When discharging from the SBR means shall be provided to avoid surges to the succeeding treatment units.
- The effluent from the SBR shall be removed from just below the water surface (below the scum level) or a device which excludes scum shall be used. All decanters shall be balanced so that the effluent will be drawn equally from the effluent end of the reactor.

To assist the design engineers in the design exercise of a SBR, typical steps involved in the design calculations are summarized in Table 3.5.

3.8 Membrane Bioreactor Systems

Principally, the membrane bioreactor (MBR) systems shall be designed using similar methodology as the activated sludge systems with additional design considerations related to the membrane filtration unit (external or internal design). The latter include provision of vacuum pressure pump, fine screen, aeration system for preventing membrane clogging, membrane back flushing and membrane cleaning system. In a MBR system, the membrane filtration unit replaces the secondary clarifier in a typical activated sludge system.

3.9 Upflow Anaerobic Sludge Blanket Systems

UASB is a form of anaerobic treatment process which combines both physical and biological processes typified by a high θ_c, high hydraulic retention time (HRT), absence of mechanical mixing and presence of internal three-phase gas/sludge/liquid (GSL) separator system.

Anaerobic treatment is an attractive treatment option for high strength industrial effluents. Reports in the literature indicate that effluents from a wide range of manufacturing industry including textile industry, petrochemical industry and landfill leachates have been successfully treated via anaerobic treatment process.

Table 3.5: Sequence of calculation for the design of SBRs. Source: (adapted from Eckenfelder, Ford and Englande, 2008)

Item Number	Common Designation	Notation	Units	Formula
1.0	**Design variables**			
1.1	Influent flow	Q_{peak}	m^3/d	-
1.2	Influent volume treated per cycle	Q_c	m^3	-
1.3	Influent BOD_5	S	mg/L	-
1.4	Cycle time (i) Feed plus aeration (ii) settling (iii) decant Total cycle time	 - - - -	 h h h h	Sum of (i) , (ii), and (iii)
2.0	**Assumed values**			
	Mixed liquor volatile suspended solids	MLVSS	mg/L	Depends on system; 2000-4000 for conventional, 4000-6000 for extended aeration
2.1	Sludge volume index	SVI	mL/g	Use upper range, typically 150
2.2	Degradable fraction	MLVSS/ MLSS	-	-
2.3	Freeboard	FB	m	-
2.4	Sidewater depth (SWD)	SWD	m	-
	Hydraulic retention time Based on Q_{avg}	HRT	h	18 to 24
3.0	**Computed values**			
3.1	Mass of mixed liquor suspended solids in one cycle	MLSS	g	MLSS mass = $\frac{Q_c(MLSS)}{(MLVSS)}$
3.2	Settled sludge volume	V_s	m^3	$V_s = \frac{(SVI)Q_c}{(10^6)(MLSS)}$
3.3	Aeration tank volume = volume for aeration plus settled sludge volume	V_R	m^3	$V_R = Q_c$ from (1.2) + V_s from (3.2)
3.4	Aeration tank area	A_R	m^2	$A_R = \frac{V_R}{SWD}$
3.5	Tank diameter	D_R	m	$D_R = \sqrt{(A_R/4\pi)}$
3.6	Tank depth	H_R	m	H_R = FB from (2.4) + SWD from (2.5)

3.9.1 Design criteria for Upflow Anaerobic Sludge Blanket Systems

The Upflow Anaerobic Sludge Blanket (UASB) systems shall be designed at average flow using the criteria shown in Table 3.6. The surface overflow rate (SOR) shall not exceed 20 $m^3/(m^2d)$ at average flow and 36 $m^3/(m^2d)$ at peak flow. The liquid upflow velocity (UV) at peak flow shall not exceed 0.9 m/h. The minimum height of the reactor (H) shall not be less than 4.0 m to accommodate sludge bed, sludge blanket and gas-liquid-solid (GLS) separator. The sludge bed height shall be in the range of 1.5 to 2.5 m. In certain circumstances, more conservative design values for all the above parameters and the parameters listed in Table 3.6 may be required and these shall be determined by the design engineer on a case to case basis.

Table 3.6: Typical design criteria for UASBs based on COD loading (Source: Ghangrekar).

Influent category	CODeff, mg/L	OLR, kgCOD/ (m^3d)	SLR, kgCOD/ (kgVSS d)	HRT, h	UV, m/h	Expected efficiency, %
Low strength	Up to 750	1.0 to 3.0	0.1 to 0.3	6 to 18	0.25 to 0.7	70 to 75
Medium strength	750 to 1000	2.0 to 5.0	0.2 to 0.5	6 to 24	0.25 to 0.7	80 to 90
High strength	1000 to 10,000	5.0 to 10.0	0.2 to 0.6	6 to 24	0.15 to 0.7	75 to 85
Very high strength	> 10,000	5.0 to 15.0	0.2 to 1.0	> 24	-	75 to 80

3.9.2 Design Methodology for Upflow Anaerobic Sludge Blanket Systems

UASB systems shall be designed based on proper selection of the following parameters: organic loading rate (OLR), solids loading rate (SLR) and hydraulic retention time (HRT) based on limitations of superficial liquid upflow velocity (UV). The reactor volume shall be determined in order to comply with the design loading criteria, and the height and cross sectional area to satisfy the upflow velocity criteria as stipulated in Table 3.6.

Reactor volume shall be determined as follows. From Table 3.6, select the upper range of OLR for the corresponding COD range. The reactor volume is then computed by using the following formula:

$$V_c = Q\ (COD_{inf})/OLR \quad \text{.....................(3.9)}$$

where:

V_c = reactor volume, m^3

Q = influent flow, m^3/d
COD_{inf} = influent COD concentration, mg/L
OLR= upper organic loading rate, $kgCOD/(m^3d)$

The height of the reactor shall be based on the liquid upflow velocity and hydraulic retention time considerations and computed according to the following equations.

Hydraulic retention time is computed using the relationship:

$$HRT_c = 24 \frac{V_c}{Q} \quad \text{............(3.10)}$$

where:

HRT_c= computed hydraulic retention time, h
V_c = computed reactor volume, m^3
Q = influent flow, m^3/d

Choose a suitable reactor height (4m-8m) and calculate the liquid upflow velocity using the following equation:

$$UV_c = H/HRT_c \quad \text{...........(3.11)}$$

where:

UV_c = calculated liquid upflow velocity, m/h
H= reactor height, m
HRT_c = calculated hydraulic retention time (from equation 3.4), h

The calculated upflow velocity shall comply with the range stipulated in Table 3.6. If the UV criterion is not met, the reactor height shall be reduced gradually until the stipulated range is satisfied while at the same time satisfying the minimum reactor height of 4.0 m. The calculation procedure shall be repeated with a new OLR if the UV criterion cannot be complied with the minimum reactor height.

Table 3.7 illustrates the sequence of calculation involved in the design of UASB reactors.

Table 3.7: Sequence of calculation for the design of Upflow Anaerobic Sludge Blanket Systems

Item Number	Common Designation	Notation	Units	Formula/Notes
1.0	**Design variable**			
1.1	Influent flow	Q	m^3/d	-
1.2	Influent COD	COD_{inf}	mg/L	-

Table 3.7 continued

2.0	**Design criteria**			
2.1	Organic loading rate	OLR	kgCOD/ (m^3/d)	Selected from Table 3.6
2.2	Solid loading rate	SLR	kgCOD/ (kgVSS.d)	Selected from Table 3.6
2.3	Hydraulic retention time	HRT	m/h	Selected from Table 3.6
2.4	Expected efficiency	-	%	-
2.5	Values			
3.0	**Computed values**			
3.1	Reactor volume	V_c	m^3	$V_c = Q(COD_{inf})/OLR$
3.2	Hydraulic Retention time	HRT_c	m/h	$HRT_c = 24V/Q$

3.10 Design Methodology for Nutrient Removal

Under the IER, the only nutrient regulated is nitrogen. Table 3.8 summarizes the various processes that can be used to remove nitrogen from industrial effluents. The processes can be categorized as biological or physical chemical processes. By enlarge, in practice, biological processes are the most commonly employed processes for nitrogen removal.

Table 3.8: Nitrogen removal processes

Biological process		**Physical chemical process**
Suspended growth	**Fixed film**	
* Nitrification	* Nitrification - trickling filter - aerobic filter	* breakpoint chlorination * ammonia stripping * ion exchange * membrane processes
* Nitrification/denitrification	* denitrification - trickling filter - fluidized bed	-

The design engineers shall follow standard design criteria, procedure and calculation steps for the design of processes to remove nitrogen from industrial effluents. Typically, the criteria and calculations involved are similar to those adopted in the design of nitrogen removal processes in sewage treatment systems. The criteria and procedure recommended by Eckenfelder, Ford and Englande (2008); Metcalf and Eddy (2003) or Qassim (1994) or other authorized design manuals are acceptable.

3.11 Design Methodology for Stabilization Ponds

Although not a commonly preferred option in Malaysia, waste stabilization ponds are sometimes employed for treating industrial effluents especially when space is not a major constraint. Various types of ponding systems are found in practice: anaerobic ponds, aerated ponds and aerated lagoons. Effluents from a variety of industries have been treated by ponding systems either as a pre-treatment or a polishing step. The industries include meat and poultry, pulp and paper, petroleum, oleo-chemicals, textile, etc. Typical design methodology for stabilization ponds is based either on kinetic concepts or empirical considerations. The former requires information on kinetic constants such as BOD removal rate constant, yield coefficient, etc., while the latter requires information on empirical data, such as BOD loading, detention time, etc., both of which may not be easily available for the industrial effluent in question. Both design methodologies are acceptable if sufficient information/data are available or reasonable assumptions can be justified. Useful design examples are illustrated and performance data for anaerobic, facultative and aerobic ponds reported in Eckenfelder, Ford and Englande (2008). The design methodology adopted by the engineer shall be properly documented.

An example of the procedure for the design of stabilization ponds based on the kinetics approach is outlined below.

The pond retention time required is calculated using the equation below:

$$t = [(L_i/L_e) - 1]\,(1/K) \qquad (3.12)$$

where:

t = retention time, d
L_i = effluent BOD, mg/L
L_e = influent BOD, mg/L
K = first-order rate coefficient for BOD removal, d^{-1}

The value of K is dependent on the effluent characteristics, hence should be determined experimentally. In the absence of experimentally determined values of K, wherever applicable, the values reported by Eckenfelder, Ford and Englande (2008) for various industrial effluents may be used. Variation of K with temperature is described by the Arrhenius equation as follows:

$$K_{T2} = K_{T1}\,\theta^{(T2-T1)} \qquad (3.13):$$

where:

K_{T2} = rate coefficient for BOD removal at temperature T2, °C
K_{T1} = rate coefficient for BOD removal at temperature T1, °C
θ = Arrhenius constant (typical value for design is between 1.05- 1.09).

The mid depth pond area is determined by using the following formula:

$$A = Qt/D \quad \text{......................(3.14)}$$

where:

- A= mid depth pond area, m^2,
- Q = volumetric flow rate, m^3/d,
- t = retention time, d
- D = the pond depth, m.

3.12 Design Methodology for Trickling Filters

Trickling filters (TFs) are commonly classified as low rate, intermediate rate and high rate filters, based on the surface or organic loading rate applied to the filters. High rate TFs have surface loading rate of 1.0 to 4.0 $m^3/(m^2d)$ and organic loading rate of 0.1 to 0.4 $kgBOD/(m^3d)$; while the values for intermediate TFs are 3.5 to 10 $m^3/(m^2d)$ and 0.2 to 0.5 $kgBOD/(m^3d)$ respectively. High rate TFs have surface loading rate of 10 to 40 $m^3/(m^2d)$ and 0.5 to 1.0 $kgBOD/(m^3d)$.

Application of trickling filters for treating industrial effluents in Malaysia is rare. However, a brief discussion of the design methodology is given below. The engineer may follow the procedure described below or any other well established methods such as the empirical model developed by the National Research Council (NRC) USA for the design of the trickling filters.

The mean retention time through the filter packing is given by the expression below.

$$t/D = CA_v^{\,m}/L_h^{\,n} \quad \text{......................(3.15)}$$

where:

- t = mean detention time, d
- D = filter depth, m
- A_v = specific surface, m^2/m^3
- L_h = hydraulic loading rate, $m^3/(m^2d)$
- C, n, m = constants dependent on packing surface characteristics and configuration.

When recirculation is practiced, the BOD applied to the trickling filter is calculated by the following equation:

$$S_o = (S_a + NS_e)/(1+N) \quad \text{...........(3.16)}$$

where :

- S_o = BOD applied to the trickling filter after mixing with the recirculated flow, mg/L

S_a = BOD of trickling filter influent, mg/L
S_e = BOD of trickling filter effluent, mg/L
N = reciculation ratio, equals to R/Q

The filter hydraulic loading can be computed from the relationship:

$$S_e / S_o = e^{-KA\ D/L\ S} \quad \text{.......................(3.17)}$$

The trickling filter volume is computed from the formula:

$$V = AD \text{................(3.18)}$$

where:
V = trickling filter volume, m^3
A = trickling filter area, m^2
D = filter depth, m

If a secondary clarifier is used downstream of the TF, the surface hydraulic loading rate shall be in the range of 16 to 32 $m^3/(m^2d)$ at Q_{avg} and 40 to 48 $m^3/(m^2d)$ at Q_{max}.

3.13 Instruments for Process Control (Performance Monitoring)

In the design of the IETS (biological processes), the design engineer shall incorporate or consider the use of the following instruments for monitoring and controlling the biological processes:

- pH meter
- ORP meter
- DO meter
- Level sensors
- Respirometer

Wherever possible, on-line continuous instrumentation systems should be preferred over manual systems. On-line pH measurement and monitoring is highly recommended where there is high fluctuation in the influent pH. On-line DO monitoring is nowadays a common feature in most activated sludge systems, hence this option of DO monitoring shall be seriously considered. On-line ORP monitoring is appropriate for both aerobic and anaerobic systems to ensure the intended biochemical processes are occurring. For large IETSs, the use of a respirometer should be explored. For MBR and UASB systems, additional performance monitoring instruments such as pressure gauge, gas analytical instruments, etc. shall be considered.

CHAPTER 4: OXYGEN REQUIREMENTS

This chapter discusses the procedure to be followed to determine the oxygen requirements for biological treatment processes and the method for sizing aeration systems.

4.1 Oxygen Requirements

Oxygen requirements for carbonaceous biochemical oxygen demand (BOD) removal include oxygen to satisfy the BOD of the effluent plus the endogenous respiration of the microorganisms. Additional oxygen is required if nitrification occurs.

Oxygen requirements depend on the influent loading to the aeration tank as well as the process design and shall be determined using rational calculations. Calculations should be based on the peak hourly BOD loading to the aeration tanks. Recycle flows from the clarifier shall be considered since these streams often have high BOD concentrations. The following formulae and procedure shall be used in the computation of oxygen requirements in the detailed design which shall be submitted to the DOE.

4.1.1 Total Oxygen Demand

Total oxygen demand for synthesis and endogenous respiration =
Oxygen demand for synthesis + oxygen demand for endogenous respiration + oxygen demand for nitrification - oxygen demand for denitrification .... (4.1)

Oxygen demand for synthesis + oxygen demand for endogenous respiration, kg/d is computed according to the following equation:

$$\text{Oxygen requirement} = 1.46Q(S_o - S) - 1.42\,P_{xv}$$

$$= Q\,(S_o - S)\left[1.46 - \frac{1.42\,Y}{1 + k_d f_b \theta_c}\right] \quad \dots (4.2)$$

where:

P_{xv} = nett sludge produced, kg/d
Q = influent flowrate, m^3/d
S_o = total BOD_5 of aeration tank influent, mg/L
S = soluble BOD_5 of aeration tank effluent, mg/L
k_d = decay coefficient, d^{-1}
f_b = biodegradable fraction of VSS immediately after generation in the system ($\theta_c = 0$)
θ_c = sludge age, d
Y = yeild coefficient, kg/kg

If the biological treatment system has been designed to achieve nitrification or nitrification is expected to occur, the oxygen requirement for nitrification shall be accounted for in the computation of the total oxygen requirement. Oxygen demand for nitrification, kg/d is given by:

$$\text{Oxygen demand for nitrification} = 4.57Q\ TKN/1000 \quad \text{..... (4.3)}$$

where :

TKN = total Kjedahl nitrogen, mg/L
= organic nitrogen (N_{org}), mg/L + ammonia nitrogen (N_{NH3}), mg/L
Q = influent flowrate, m^3/d

The oxygen demand for nitrification computed from equation (4.3) will need to be added to the value of oxygen demand obtained from equation (4.2). The total oxygen requirement is designated as actual oxygen requirement (AOR), kg/d.

4.1.2 Standard Oxygen Transfer Rate

Standard oxygen transfer rate (SOTR), kg/d is computed from the following equation:

$$SOTR = \frac{AOR\ C_{S\ @20^\circ C}}{[\beta C_S - C_{L@20^\circ C}]\ \chi\theta^{T-20}} \quad \text{............(4.4)}$$

(neglecting altitude correction factor)

where:

AOR = actual oxygen requirement, k_gO_2/d
$C_{s@20^\circ C}$ = oxygen saturation concentration in clean water at standard condition, mg/L
β = ratio of oxygen saturation concentration in effluent and clean water
C_S = oxygen saturation concentration at temperature T, mg/L
C_L = oxygen concentration to be maintained in the bio-reactor at temperature T, mg/L
χ = ratio of total oxygen transfer in effluent and clean water
T = temperature of effluent in aeration tank, °C

4.1.3 Air Flowrate

Air flowrate, kg air/d is computed as follows:

$$\text{Air flowrate} = \frac{SOTR}{fO_2 SOTE} \qquad \text{....(4.5)}$$

where :

SOTR = standard oxygen transfer rate, kgO_2/d
fO_2 = fraction of oxygen in air, kgO_2/kg air (typically, f = 0.23)
SOTE = standard oxygen transfer efficiency, %

4.1.4 Aeration System Power Requirement

For mechanical aeration, the required power, kWh is computed from the following formula:

$$\text{Required power} = \frac{SOTR}{OTE} \qquad \text{....(4.6)}$$

where :

SOTR = standard oxygen transfer rate, kgO_2/d
OTE = oxygen transfer efficiency, kgO_2/kWh

Power level, W/m^3 is given by:

$$\text{Power level} = \text{Required power, kWh x } 1000/V \qquad \text{....(4.7)}$$

where :

V = volume of aeration tank, m^3

For diffused aeration, the engineer shall state clearly the type of diffusers used: fine or course bubble diffusers or combination systems. The aerator power requirement is computed via the following steps. Firstly the air flowrate, m^3/d is determined as follows:

$$(R_{air\ actual}) \text{ air flowrate, m}^3\text{/d} = \frac{SOTR}{\rho_{air(20°C)}\ fO_2 SOTE} \qquad \text{....(4.8)}$$

where :

SOTR = standard oxygen transfer rate, kgO_2/d

ρ_{air} = specific gravity of air (typically, ρ_{air} = 1.2 kg/m^3)

Adopted ($R_{air\ adopted}$) = $R_{air\ actual}$ x safety factor (typically, safety factor = 2.0)

Power requirement is then computed according to the following equation:

$$P = \frac{Q\rho g\,(d_i + \Delta H)}{\eta} \qquad .....(4.9)$$

where:

P	=	power required, W
Q	=	influent flowrate, m^3/d
ρ	=	density of water, kg/m^3
g	=	acceleration due to gravity, m/s^2
d_i	=	depth of aeration tank, m
ΔH	=	head loss in the air piping, m
η	=	motor efficiency

4.2 Aeration Requirement Calculation Procedure

To assist the design engineer in a step-by-step calculation of the oxygen requirement and in the sizing of aeration system, the calculation sequence is tabulated in Table 4.1.

4.3 General Requirements in Aeration System Design

Multiple mechanical aeration unit installations shall be designed to meet the maximum oxygen demand with the largest unit out of service. Additionally, the design shall consider or incorporate energy efficiency features, which may include the following:

- use of high energy efficiency pumps and motors
- use of remote control system such as SCADA system
- use of variable frequency drives (VFD)
- preparation of equipment maintenance plan (especially of pumps)

A spare aeration mechanism shall be made available for single unit installations. Access to the aerators shall be provided for routine maintenance.

4.4 Dissolved Oxygen Monitoring

For aerobic processes, the dissolved oxygen in the bioreactors must be monitored on continuous basis, preferably with a dissolved oxygen sensor installed at the bioreactors which is linked to the computer system in the control room. Manual dissolved oxygen monitoring is allowed for Q< $60m^3/d$ only.

Table 4.1 : Sequence in the calculation of oxygen requirements and the required power of aeration system

Item Number	Item	Common Designation	Unit	Equation
A. Oxygen Calculation				
1.0	**AOR**	**Actual oxygen required**		
1.1	S_r	BOD load removed	$kgBOD_5/d$	$S_r = Q_{av}(BOD_{tot\ infl} - BOD_{sol\ eff}$ $= Q(S_o\text{-}S)/1000$
1.2	a'		$kgO_2/$ $kgBOD_5$	$a' = (BOD_u/BOD_5) - (BOD_u/X_b)Y$
1.3	b'		$kgO_2/$ kgVSS	$b' = (BOD_u/X_b)f_bk_d$
1.4	$a'S_r$	Oxygen demand for synthesis	kgO_2/d	Demand for synthesis $= a'S_r$
1.5	$b'X_vV$	Oxygen demand for endogenous respiration	kgO_2/d	Demand for endogenous respiration $= b'X_vV$
1.6	O_{2tot}	Average total oxygen demand	kgO_2/d	Average total demand $= a'S_r + b'X_vV$
1.7	Q_{max}/Q_{av}	-	-	-
1.8	AOR	Total oxygen demand at Q_{max}	kgO_2/d	$AOR = \frac{Q_{max}}{Q_{av}}(a'S_r + b'X_vV)$
B. Power Calculation				
2.0		**Mechanical Aeration**		
2.1	SOTE	Standard oxygen transfer efficiency	$kgO_2/$ kWh	-
2.2	$P_{required}$	Total required power	kW	$P_{required} = SOTR/SOTE$
2.3	$P_{each\ aerator}$	Required power for each	kW	$P_{each\ aerator} = \frac{P_{required}}{\text{no of aerators}}$
2.4	$P_{T\ installed}$	Total power aerator installed	kW	-
2.5	P_{level}	Power level per m^3 of aeration tank	W/m^3	$P_{level} = \frac{P_{T\ installed}}{V}$
3.0		**Diffused aeration**		
3.1	SOTR	Standard oxygen transfer rate	kgO_2/d	$SOTR = \frac{(AOR)C_{S\ @\ 20°C}}{\beta(C_S - C_L)\chi\theta^{(T-20)°C}}$
3.2	$R_{air\ theoretical}$	Theoretical flowrate of air required	m^3/d	$R_{air\ theoretical} = \frac{SOTR}{(\rho_{air@20°C})(fO_2 \text{ in air by weight})}$
3.3	$R_{air\ actual}$	Actual flowrate of air required	m^3/d	$R_{air\ actual} = \frac{R_{air\ theoretical}}{SOTE}$

CHAPTER 5: NUTRIENT REQUIREMENTS

Many industrial effluents do not contain sufficient amounts of nutrients particularly nitrogen (N) and phosphorus (P) for optimal microbial growth: These nutrient – deficient industrial effluents need to be supplemented with nutrient addition. Based on experience, the design engineer shall identify the need for nutrient addition and compute the amount required. Typically, as a practical rule of thumb, for conventional activated sludge systems, the BOD5:N:P ratio to be maintained in the influent to the aeration tank is 100:5:1. The associated equipment and instrumentation to ensure adequate supply of nutrient to the biological treatment process shall be designed accordingly. This includes the nutrient tank, agitation system, dosing and metering system and nutrient storage requirement. The nutrients to be supplied should be in the forms which are readily assimilated by the microorganisms. Activated sludge systems operated at high sludge ages will require less nutrients due to the lower production of excess sludge. As a guide, Table 5.1 shows industrial effluents which have been found to be nutrient deficient.

Table 5.1 Nutrient deficient industrial effluents
(Source: Adapted from Broderick and Sherrard, 1985)

Effluent From Industry	Deficient Nutrient
Bakery	N
Bottling plant	N, P
Brewery	N
Chemical plant	P
Coffee manufacture	N
Coke oven	P
Corn processing	N
Cotton kiering	N
Dairy products	N, P
Food processing	N, P
Fruits and vegetables	N, P
Pulp and paper	N, P
Pharmaceutical	P
Pineapple processing	N, P
Rag and rope	N, P
Textile	N

CHAPTER 6: DESIGN OF CLARIFIERS

Sometimes in the treatment of industrial effluents, pretreatment for the removal of suspended solids is required before the effluent is sent to a biological treatment process to remove dissolved organics. If the concentration of suspended solids in the raw effluent is low, primary sedimentation is not required. If the solids present are organic in nature, a certain fraction of the biochemical oxygen demand is also removed through the sedimentation process in the primary clarifier which is normally achieved by gravity sedimentation. Clarifiers are also required after the industrial effluent has undergone biological treatment in the aeration tank to separate the biological solids from the liquor. This is accomplished in the secondary clarifiers. In chemical treatment processes too, for example in the removal of metals via precipitation process, the metal precipitates need to be separated from the solution by clarification process. This chapter describes the design considerations to be taken into account by the engineer when designing clarifiers.

The most important aspect in the design of clarifiers is the computation of the required surface area of the clarifier. This is usually determined by considering the following design parameters: surface overflow rate (SOR), solids loading rate (SLR), hydraulic retention time (HRT) and weir overflow rate (WOR).

6.1 Primary Clarifiers

6.1.1 Design Criteria for Primary Clarifiers

Primary clarifiers shall be designed using the design criteria stipulated in Table 6.1 and 6.2. Among the design parameters listed in Table 6.1, the two most important parameters for the design of primary clarifiers are surface overflow rate (SOR) and hydraulic retention time (HRT). Table 6.2 gives the recommended physical dimensions of the rectangular and circular primary clarifiers.

Table 6.1: Typical design criteria for primary clarifiers
(Source: Adapted from Metcalf and Eddy, 2003)

Design Parameter	Unit	Design Criteria	
		Range	Typical
SOR at Q_{max}	$m^3/(m^2d)$	30 to 50	40
SOR at Q_{avg}	$m^3/(m^2d)$	80 to 120	100
SLR at Q_{max}	$kg/(m^2d)$	-	30
HRT	h	1.5 to 2.5	2.0

Table 6.2: Typical design criteria (physical dimensions) for rectangular and circular primary clarifiers.
(Source: Metcalf and Eddy, 2003)

Design Parameter	Unit	Rectangular		Circular Tank	
		Range	Typical	Range	Typical
Depth	m	3.0 to 4.5	3.6	3.0 to 4.5	3.6
Length	m	15 to 90	24 to 40	-	-
Width	m	3 to 24	5 to 10	-	-
Diameter	m	-	-	3 to 60	12 to 45
Bottom slope	%	-	-	6 to 17	8

6.1.2 Design Methodology for Primary Clarifiers

Using the values of Q_{max} and Q_{avg} and the values of SOR from Table 6.1, the corresponding clarifier surface areas are computed using equation (6.1). The larger value of A shall be adopted for the design. The physical dimensions of the primary clarifier shall then be decided to comply with the recommended criteria stated in Table 6.2.

6.2 Secondary Clarifiers

6.2.1 Design Criteria for Secondary Clarifiers

Secondary clarifiers shall be designed according to either one of the following methods: the conventional hydraulic loading rates and solids loading rates approach or the limiting solids flux approach. If the former method is used, the design criteria stipulated in Table 6.3 shall be complied with.

Table 6.3: Typical design criteria for secondary clarifiers
(Source: Adapted from Metcalf and Eddy, 2003; WEF, 1992; V Sperling, 2007)

Type of biological Treatment System	SOR, $m^3/(m^2.d)$		SLR, $kg/(m^2.d)$		WOR, $m^3/(m^2.d)$	
	Q_{avg}	Q_{max}	Q_{avg}	Q_{max}	Q_{avg}	Q_{max}
CAS	16 to 31	40 to 64	96 to 144	240	120	300
EAAS	7 to 16	24 to 31	24 to 120	168	120	300

Note: CAS = conventional activated sludge; EAAS = Extended aeration activated sludge

6.2.2 Design Methodology for Secondary Clarifiers

The procedure for designing a secondary clarifier using the conventional approach involves calculations as outlined below.

(a) Clarifier's surface area based on SOR

From Table 6.3, determine the SOR (or hydraulic loading rate-HLR) corresponding to Q_{av} and Q_{max}. Calculate the area required (A) for Q_{av} and Q_{max} by using the formula:

$$A = \frac{Q}{SOR} \quad \text{.........(6.1)}$$

where:

A = surface area of clarifier, m^2
Q = influent flow rate, m^3/d
SOR = surface overflow rate, $m^3/(m^2.d)$

(b) Clarifier's surface area based on SLR

From Table 6.3, determine the SLR corresponding to Q_{av} and Q_{max}. Calculate the area required (A) for Q_{av} and Q_{max} by using the formula:

$$A = \frac{(Q + Q_r) X}{1000 \ SLR} \quad \text{.........(6.2)}$$

where:

A = surface area of clarifier, m^2
Q = influent flow rate, m^3/d
Q_r = recycle flow rate, m^3/d
X = MLSS in the aeration tank, mg/L
SLR = surface loading rate, $m^3/(m^2.d)$

(c) Clarifier's surface area to be adopted for design

From the four values of clarifier's surface area (A) obtained in(a) and (b), the largest value of A shall be adopted for the design.

(d) Clarifier's diameter of a circular clarifier

Calculate the diameter (D) using the formula:

$$A = \frac{\pi D^2}{4} \quad \text{........(6.3)}$$

where:

A = surface area of clarifier, m^2
D = diameter of clarifier, m

(e) Weir length (W)

Calculate the weir length (L_{weir}) using the formula:

$$L_{weir} = \pi (D - 2d) \quad ....(6.4)$$

where:

L_{weir} = weir length, m

D = diameter of clarifier, m

d = separation distance from weir crest to side wall, m

(f) Weir overflow rate (WOR)

Calculate the weir overflow rate (WOR) and ensure it complies with the recommended criteria stipulated in Table 6.3. WOR is computed by using the formula:

$$WOR = \frac{Q}{L_{weir}} \quad ....(6.5)$$

where:

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

Q = influent flow rate, m^3/d

L_{weir} = weir length, m

(g) Hydraulic retention time (HRT)

Calculate the hydraulic retention time (HRT) at Q_{av} and Q_{max} and ensure it is within the recommended range as shown in Table 6.1. HRT is calculated by using the formula:

$$HRT = \frac{V}{Q} \quad ....(6.6)$$

where:

HRT = hydraulic retention time, h

Q = influent flow rate, m^3/h

Similar calculation steps are involved in the design of rectangular clarifiers. However, the formulas in step (d) and (e) need to be modified accordingly.

It is recommended that the design of secondary clarifiers for an existing industry follow the limiting solids flux approach. The procedure described in several references such as Metcalf and Eddy (2003) and Eckenfelder, Ford and Englande (2008) may be followed where settling data on the industrial effluent in question are obtained from laboratory tests. In the case of a new industry, the design of secondary clarifiers can also be accomplished by using the limiting solids flux approach based on data on operating clarifiers compiled and summarized by von Sperling (2007).

6.3 Sludge Depth Monitoring

A method of measuring and monitoring the sludge depth in the clarifier shall be identified. If deemed appropriate, a sludge level sensor may be selected and installed by the design engineer to continuously monitor the sludge level and to facilitate the necessary operational actions to ensure effective control of the clarifier and smooth operation of the IETS.

6.4 Design Criteria for Inclined Plate Clarifiers

In industrial effluent treatment applications, a very common group of clarifiers used to settle solids is the inclined plate clarifiers. Of the three types of inclined clarifiers, the most popular one is the Lamella clarifier which has been used in the industry for small flows such as those encountered in metal finishing operations as well high flows typically found in pulp and paper mills. Other applications include printed circuit board manufacture, food processing, and steel mills.

Typical design criteria are surface overflow rate (SOR) and angle of inclination which are given in Table 6 .4.

Table 6.4: Typical design criteria for lamella clarifiers

Design parameter	Unit	Typical range
SOR*	L/(m². min)	10 to 40
Angle of inclination (ά)**	degree	45° to 60°
Weir	L/(m. min)	<80

Note
SOR is also referred to as areal loading
* lower values are used for light solids (e.g. metal hydroxides) and higher values fro heavier solids (e.g. pulp and paper effluent solids)
** lower values are used for light solids and higher values fro heavier solids

6.4.1 Design Methodology for Inclined Plate Clarifiers

The ratio of clarification to thickening area is preferably determined from laboratory settling tests of representative effluent samples for existing industries or from past experience with similar applications for new industries.

The clarifier settling area required shall be computed from the relationship:

$$A = Q/SOR \quad \text{............(6.7)}$$

where:

A = area required for settling, m^2
Q = influent flowrate, L/min
SOR = surface loading rate, L/(m^2. min)

The number of plates required shall be calculated from the formula:

$$A_p = n\,A\cos\acute{\alpha} \quad \text{.........(6.8)}$$

where:

A_p = projected settling area, m^2
n = number of plates
A = area of each plate, m^2 (to be obtained from the plate manufacturer)
$\acute{\alpha}$ = inclination angle

The engineer shall compute and submit the following information:

- flow rate
- type of clarifier
- angle of inclination
- surface over flowrate
- plate area
- total effective settling area
- ratio of clarification to thickening area
- plate spacing
- sludge storage compartment
- use of coagulants and flocculants, if relevant

An inlet plenum shall be provided to uniformly distribute the influent to the inclined plate compartments. The outlet area shall be designed to force uniform flow from all plate compartments and also over the entire with of the plates.

The design shall incorporate features to inhibit channeling. A sufficient sludge compartment to store the accumulated solids shall also be provided in the design.

CHAPTER 7: DESIGN OF pH ADJUSTMENT SYSTEM

If the influent to the biological treatment process is expected to exhibit pH outside the optimal range for biological treatment, pH adjustment system shall be provided. pH adjustment may also be required to prepare effluent for physical chemical treatment processes such as coagulation or for metal precipitation or for final effluent pH correction before discharge. pH adjustment is typically accomplished by using acids or alkalis.

7.1 Design Criteria for pH Adjusment Tanks

The sizing of the neutralization or pH adjustment tank shall be based on the average flow and the acceptable residence time commonly used in practice. The general equation used to be to compute the tank volume (V) is:

$$V = Q_{avg} \times \text{residence time} \qquad \text{............ (7.1)}$$

where:

V = tank volume, m^3

Q_{avg} = average effluent flow rate, m^3/min

The minimum residence time shall be 10.0 min. The above equation is also used to size up other tanks such as precipitation tanks, coagulation and flocculation tanks, redox tanks, etc.

7.2 Instrumentation for Process Control (Performance Monitoring)

The design of the neutralization system shall be an automatic system that includes mixer and level controls, automatic chemical addition, automatic pH monitoring, automatic filter feed pump and control panel. If incoming effluent streams exhibit wide fluctuations in pH hence are subjected to wide swings in reagent demand, a two-stage pH adjustment system should be used.

The design engineer shall indicate clearly and design properly the following:

- flowrate; retention time
- dimensions of the tank
- characteristics of pH adjustment chemicals to be used
- capacity of metering pumps and associated dosing equipment
- type of the pH adjustment system-batch or continuous; single stage or double stage

CHAPTER 8: DESIGN OF CHEMICAL PRECIPITATION SYSTEMS

Chemical precipitation is the most common technique used for removing dissolved metals from metal bearing industrial effluents. The ionic metals are converted to an insoluble form by the chemical reaction between the soluble metal compound and the precipitating agent. The unit operations typically involved in this technique include pretreatment, precipitation, coagulation and flocculation, solid-liquid separation and dewatering. This chapter is dedicated to the discussion of chemical precipitation systems especially to remove metals from industrial effluents.

8.1 Precipitation of Metals as Hydroxides

The most widely used chemical precipitation is hydroxide precipitation where dissolved metals are converted to an insoluble form by the use of an alkaline precipitant such as sodium hydroxide to reduce the solubility of the dissolved metals. Some metals can also be precipitated as sulfides, carbonates, sulfates or chlorides.

8.1.1 Pretreatment for Metal-Complexes

If metal chelating or complexing agents [e.g. organic acids, such as tartaric acid, oxalic acid; cyanide; organo-metals; ethylene diamine tetraacetic acid (EDTA); ammonia, citrates or phosphates] are present in the effluent, the design engineer shall explain how the effluent is to be pretreated prior to metals precipitation process. The pretreatment step shall then be incorporated in the design of the chemical precipitation system.

8.1.2 Design Criteria and Instrumentation System for Process Monitoring (Performance Monitoring)

The working pH for precipitating the metals shall be decided primarily based on the information obtained from the graph of metals solubility versus pH. As a result of the presence of other constituents in the effluent stream, the pH of minimum solubility may change slightly. The situation may be further complicated by the presence of other metals in the raw effluent stream. This is common for effluents generated from electroplating processes involving plating of more than one metal. If more than one metal is to be precipitated, a pH value that is applicable to all metals to produce effluent that complies with the discharge standards for all the metals shall be identified. Alternatively, each metal may be separately precipitated in different stages.

The design engineer shall explain how the pH range has been selected for the precipitation system to effectively precipitate all the relevant metals regulated by the Industrial Effluent Regulations 2009 (IER). The residence time to be provided in the precipitation tank shall be typically, not less than 30 minutes.

To maintain a reasonably constant pH of the solution, the engineer shall design a suitable mode of control for reagent addition which could be in the form of gravity feeding through a proportioning valve or via the use of variable speed pumps or any other control system.

8.1.3 Instrumentation for Process Control (Performance Monitoring)

The efficiency of treatment process to precipitate the metals is highly dependent on pH of the aqueous solution. hence continuous and accurate pH monitoring is imperative. The design engineer shall incorporate instrumentation system to monitor pH continuously, which is interlocked with the chemical dosage system. If the treated effluent is to be further treated in a biological treatment process, pH readjustment shall be required. Hence in this case, the engineer shall ensure the requirement for another pH meter is catered for in the design.

8.1.4 Clarification

Lamella type clarifiers are commonly employed to separate the precipitated metals from the aqueous phase. The design of clarifiers shall follow the specifications stipulated in Chapter 6 on the Design of Clarifiers. In certain applications, polishing filters such as multimedia filters may be used downstream of the clarifier to remove suspended solids not effectively removed by clarification. The design of polishing filters shall follow typical design procedure commonly adopted by design engineers which shall be documented and submitted with the notification package.

8.2 Design Criteria for Metal Sulfide Precipitation Systems

If sulfide precipitation is used, the considerations to be taken into account by the design engineer shall include:

- Type of sulfide compound to be used
- Minimum detention time required
- Mixing requirement
- pH range to be maintained
- Method of control of hydrogen sulfide evolution
- Need for air pollution control, if deemed necessary.
- Instrumentation for performance monitoring

8.3 Design Criteria for Other Metal Precipitation Technologies

If any other precipitation technology is used such as carbonate, sulfate or chloride technology, the design engineer shall include the following considerations in the design:

- Type of chemical to be used
- Minimum detention time
- Mixing requirement
- Instrumentation for performance monitoring

CHAPTER 9: DESIGN OF COAGULATION AND FLOCCULATION SYSTEMS

Chemical precipitation is usually followed by coagulation and flocculation. The design engineer shall describe the chemical coagulants and flocculants to be used and their characteristics and details of application as recommended by the manufacturer. Results of jar test experiments to investigate the optimum application conditions such as pH, dosage and removal efficiency shall be presented.

9.1 Design Criteria for Coagulation System

The design engineer shall design high-energy rapid-mix condition to provide sufficient mixing of the coagulants. The contact time required in the rapid- mix chamber shall be typically 1 to 3 minutes. However, it is recognized that the optimum retention time is dependent on the velocity gradient and coagulant dosage applied.

The design engineer shall provide a root mean square velocity gradient (G) of the order of 300/s for back mix reactors and 400/s to 1000/s for plug-flow in-line reactors. Gt shall be in the range of 10,000 to 20,000.

9.2 Design Criteria for Flocculation System

Flocculation is a slow mixing process to promote agglomeration of coagulated solids. It is accomplished by equipping the flocculators with slowly rotating paddles or other moving devices. The design engineer shall ensure the design meets the criteria stated in Table 9.1 for the average root mean square velocity gradient (G).

Table 9.1: Average G for flocculation of different types of flocs

Type of Flocs	G, s^{-1}
Fragile flocs such as biological flocs	10 - 30
Medium strength (turbidity flocs)	20 - 50
Chemical precipitation floc	40 - 100

Note : G is the root mean square velocity gradient.

In the flocculation chamber, the design engineer shall ensure a design contact time in the range of 20 minutes to an hour or more. Gt shall be in the range of 20,000 to 60,000.

9.3 Equipment Components and Instrumentation System for Process Monitoring (Performance Monitoring)

All required components (such as chemical feed system) and relevant instrumentation and controls (such as in-line pH measurement system) shall be incorporated in the design.

CHAPTER 10: DESIGN OF OXIDATION REDUCTION SYSTEMS

The oxidation reduction systems are typically used in the treatment of chromates and cyanides where chromates undergo reduction while cyanides undergo oxidation. For the removal of hexavalent chromium, sodium bisulfite or sulfur dioxide is added to reduce chromium to trivalent chromium. In the case of cyanide, chlorine or sodium hypochorite is used to oxidize the cyanide, followed by the hydrolysis of cyanogen chloride to form cyanate. This chapter is dedicated to the discussion of the treatment of chromates using oxidation-reduction technique while the design of cyanide treatment process is discussed in Chapter 11.

10.1 Removal of Chromium

Industrial effluents containing hexavalent chromium such as chromates and dichromates are commonly treated by a two-step process where in the first step, hexavalent chromium (Cr^{6+}) is reduced to trivalent chromium (Cr^{3+}) and in the second step, the trivalent chromium is precipitated as chromium hydroxide.

As the oxidation – reduction potential (ORP) and the speed of the reduction reaction are intimately affected by the pH of the solution, the monitoring of pH and ORP is essential to ensure proper control of the reduction process. Typical reducing agents used in the first stage of the process are sodium bisulfite or sulfur dioxide.

In the second stage, hydroxide precipitation is accomplished by the addition of alkaline solution such as sodium hydroxide.

10.2 Design Criteria and Instrumentation for a Two Stage Chromium Removal System

For a typical two stage chromium removal system, two pH control systems and one ORP systems shall be provided. All three controllers should be the on/off type that have a control relay with adjustable dead band. It is also recommended that the controllers also have alarm relays to alert the operator of conditions outside the normal range. For a two stage oxidation-reduction system a typical design and control system shall consist of the following features:

- A pH meter shall be installed in the first tank where with the addition of acid, the pH shall be maintained at a value in the range of 2 to 3.
- An ORP meter shall be also installed in the first tank where after the addition of reducing agent the ORP shall be maintained at a value of approximately + 250 to + 300 mV range.
- The reaction time in the first stage shall be typically 10 to 30 mins. The reaction time increases if pH is controlled at higher levels. Variations in pH also affect the measured ORP. Therefore pH shall be held constant to achieve consistent ORP control.

- A pH meter shall be installed in the second tank where through the addition of alkaline solution, the pH shall be maintained at a pH of 8 to 9.

Table 10.1 summarizes the design criteria for a two-stage chromium removal treatment process which the engineer shall comply with.

Parameter	Unit	Set points / Range
First tank		
pH	value	Range: 2 to 3
ORP	mV	Range: +250 to +300
Residence time	min	Range: 10 to 30
Second tank		
pH	value	Range: 8 to 9
Residence time	min	Range: 10 to 30

The design engineer shall describe the type of system to be used and identify the details of the chemicals and process conditions to be maintained, including the following aspects:

- whether the process is a continuous or a batch process
- the reducing agents and the alkaline chemicals to be used and the reagent feed systems
- whether coagulants and flocculants will be used and the types, chemical names, properties, application and recommended dosage
- pH and ORP values to be maintained in the tank
- pH and ORP meters and controllers to be used and where the meters will be installed
- process and instrumentation diagram (PID) showing how pH and ORP measurements are linked to the chemical dosing system.
- Mixer
- Transfer pumps and level controllers

CHAPTER 11 : TREATMENT OF CYANIDE EFFLUENT STREAMS

Electroplating shops usually generate dilute cyanide effluents streams which are typically treated via a two-stage process commonly known as alkaline chlorination. It has been reported in the literature that a properly designed, maintained and operated alkaline chlorination system will oxidize cyanides amenable to chlorination and produce good quality effluents. However, alkaline chlorination will not destroy stable cyanide complexes such as ferrocyanides or ferricyanides.

Additionally, copper, nickel and precious metal cyanide complexes require excess chlorine for effective cyanide destruction.

11.1 The Design Criteria for Alkaline Chlorination Process

The design for a two stage alkaline chlorination process shall incorporate separate tanks for each stage. Exception is allowed only for batch treatment system where one tank can be employed.

In the first stage where hypochlorite is used to oxidize cyanide to cyanate, the pH of the solution shall be maintained at pH 10 or higher, preferably in the range of 11.0 to 11.5. The minimum oxidation period shall be designed to be 10 min although longer retention times are commonly used in practice. The ORP set-point shall be controlled at approximately +325 mV with the maximum being +400 mV. During treatment, the engineer shall provide vigorous mixing of the solution to ensure uniform composition throughout the reaction tank and to prevent the production of solid cyanide precipitates that resist chlorination.

In the second stage, the cyanate is oxidized to carbon dioxide and nitrogen through the addition of additional hypochlorite. The pH shall be maintained in the range 8.5 to 9.0. The ORP set point is between +600 mV to +800 mV to indicate a complete reaction. The engineer shall ensure a minimum retention time of 30 minutes, although retention times of 120 minutes are commonly employed in practice.

Table 11.1 summarizes the design criteria for alkaline chlorination process which the engineer shall comply with.

The engineer shall determine the following and design the alkaline chlorination system accordingly:

- pH set points
- retention time
- ORP set-points
- vessel size and geometry
- ORP set-points

- vessel size and geometry
- amount of chlorine required
- agitation requirements
- reagent delivery system
- solids removal system

Table 11.1: Design criteria for an alkaline chlorination process

Parameter	Unit	Set points / Range
First tank		
pH	value	Range: 10.0 to 11.5
ORP	mV	Range: +325 to +400
Residence time	min	Range: 10 to 60
Second tank		
pH	value	Range: 8.0 to 9.0
ORP	mV	Range: +600 to +800
Residence time	min	Range: 30 to 120

11.2 Instrumentation for Process Control (Performance Monitoring)

In the continuous process, the design engineer shall provide automatic instrumentation to control reagent dosing and to measure pH, ORP and temperature on continuous basis.

11.3 Treatment of Concentrated Cyanide Wastes

Concentrated cyanide wastes, such as spent plating or stripping solutions shall be treated separately either by electrolytic oxidation or thermal destruction or by other proven technologies. The concentrated cyanide waste streams shall not be reacted with hypochlorite to avoid the violet reaction which emits toxic chlorine gas.

11.4 Alternative Treatment for Cyanide Waste

There are several alternatives to alkaline chlorination process for treating cyanide effluent streams. These include the use of ozone, hydrogen peroxide, calcium hypochlorite, electrochemical oxidation, thermal oxidation and precipitation. If any of these alternative technologies is used, the design engineer shall ensure that proven and well established design criteria are used in the design process, which shall be submitted to the DOE.

CHAPTER 12: ION EXCHANGE

Ion exchange is a reversible chemical reaction where an ion from solution is substituted for a similarly charged ion attached to an immobile solid surface. Typically in industrial application to treat industrial effluent streams, synthetically produced organic resins are used as solid exchange surfaces. Ion exchange treatment has been widely used in the industry to remove various contaminants from industrial effluents, particularly metals.

12.1 General Considerations Design for Ion Exchange Columns

The engineer shall provide details of the following aspects/considerations and design the ion exchange column accordingly:

- type of resin:
  - strong acid cation
  - weak acid cation
  - strong base anion
  - weak base anion
- segregation of effluent streams containing high concentration of suspended solid (SS)
- pH adjustment
- resin capacity
- amount of resin required and resin depth
- number of columns and column dimensions
- mode of column operation
  - batch or fixed bed or moving bed
  - co current or countercurrent
- hydraulic loading rate
- metals – selective chelating resins
  - selectivity coefficient
- cycle time
- breakthrough time.
- electrowining (if appropriate)

Typical design criteria and column dimensions are:

Diameter = 1 to 2 m
Height = 3 to 4 m
Influent HLR = 0.5 to 7.0 L/(m^2.s)
Regeneration solution HLR = 0.7 to 1.5 L/(m^2.s)

12.2 Design of Fixed Ion Exchange Columns Based on Kinetic Approach

Ion exchange columns can be designed by using either the scale-up approach or the kinetic approach. Both approaches require a laboratory or pilot plant study to establish the breakthrough curve for the pollutant to be removed from the effluent stream. The Thomas kinetic equation commonly used for the design of ion exchange columns is given by:

$$\ln (C_o/C - 1) = \frac{k_1 q_o M}{Q} - \frac{k_1 C_o V}{Q} \quad ....(12.1)$$

Where:

C_o = influent ion concentration, mg/L or meq/L
C = effluent ion concentration, mg/L or meq/L
k_1 = rate constant, L/(d.eq)
q_o = maximum solid phase ion concentration, eq/kg resin
M = mass of resin, kg
V = throughput volume, L
Q = design effluent flowrate, L/d

Breakthrough is considered to have occurred when $C = 0.05C_o$ and the column is assumed to have exhausted when $C = 0.95C_o$.

The amount of resin required is calculated by using equation (12.1) when the breakthrough time (t) is fixed at a certain reasonable value. Alternatively, by fixing M, the column breakthrough time can be determined. Throughput volume (V) is related to breakthrough time (t) through the following relationship:

$$V_B = Qt \quad ....(12.2)$$

where:

V_B = throughput volume at breakthrough time, L
Q = design effluent flowrate, L/d
t = breakthrough time, d

Throughput volume (V) at exhaustion is also determined by using equation (12.1) by assuming $C = 0.95\ C_o$.

12.3 Instrumentation for Process Control (Performance Monitoring)

The engineer shall identify pertinent process parameters that require close monitoring to ensure optimal operation of the ion exchange system. Typically, automatic controls are provided for the following:

- pH, if pH adjustment is required;
- level sensors to monitor the level in the dosing tank;
- no flow alarm and regenerant sensing;

Method of monitoring and detecting the breakthrough time, such as conductivity monitoring, use of specific ion probes, colorimetric analytical methods or methods based on column elapsed time or flow through, must be specified by the design engineer. Relevant instruments must be incorporated in the design.

12.4 Handling of Process Residuals

Process residuals from ion exchange system are the regenerant waste stream and the backwash solution. Both effluent streams shall be treated to meet the stipulated discharge standards prior to discharge.

The regenerant effluent stream is highly concentrated and if the ion exchange system is removing metals, an electrowining process should be considered, if deemed appropriate.

12.5 Off-site Regeneration

If off-site regeneration of ion exchange columns is proposed, the engineer and the owner shall take the necessary actions to ensure compliance with other relevant regulations, such as the Scheduled Waste Regulations 2005.

CHAPTER 13: DESIGN OF OIL-WATER SEPARATORS

Industrial effluents from a wide range of industries contain oil which needs to be removed prior to discharge to the environment by employing oil water separators which are available in different types and designs.

13.1 General Considerations Design for Oil-Water Separators

The design engineer shall specify and take into considerstion the following in the the design of oil-water separators:

13.1.1 Fluid Properties

- effluent flowrate
- effluent temperature
- effluent absolute viscosity
- total oil concentration (free, emulsified, and dissolved)
- specific gravity of oil and water phases
- effluent solids content

13.1.2 Type of Separators

<u>Coalescing plate separators</u>

- wetted plate area
- mean plate spacing
- oil skimmer type
- shape of plates
- plate materials

<u>Gravity settling tanks</u>

- projected plan area
- inlet design
- exit design
- aspect ratio
- oil skimmer design

<u>Ultrasonic separators</u>

- hydroclone nominal size
- reject orifice size
- separator swirl number

13.1.3 Mode of Operation

- Batch treatment mode or continuos operation

13.1.4 Pretreatment of Emulsified Oil

The method chosen for the pretreatment of emulsified oil shall be clearly described and incorporated in the design of the oil-water separator. Pretreatment techniques include pH adjustment, physical, chemical or heat treatment.

13.1.5 Oil separation efficiency

Efficiency is calculated by using the formula:
Oil removal efficiency

$$(\%) = \frac{100 \times (C_{in} - C_{out})}{C_{in}} \quad \text{............... (13.1)}$$

where:

C_{in} = inlet oil concentration, mg/L
C_{out} = outlet oil concentration, mg/L

Where ever possible, the engineer shall provide oil separator perfomance curve.

13.2 Design Criteria for Gravity Oil-Water Separators

The following is a summary of the important considerations and relevant equations typically used in the design of an oil-water separator.

The vertical velocity or rise rate of the oil globule is calculated by using the formula:

$$V_t = \frac{g(\rho_w - \rho_o) D^2}{18\mu} \quad \text{.......(13.2)}$$

where:

V_t = vertical velocity or rise rate of the oil globule, cm/s
g = acceleration due to gravity, cm/s^2
ρ_w = density of water, g/cm^3
ρ_o = density of oil, g/cm^3
D = diameter of oil globule to be removed, cm
μ = absolute viscosity of effluent, poise

The mean horizontal velocity (V_H) is calculated by:

$$V_H = 15\, V_t \leq 15.2 \text{ cm/s} \quad \text{.........(13.3)}$$

where:

V_H = mean horizontal velocity, cm/s
V_t = vertical velocity, cm/s

15.2 cm/s is the recommended upper limit for the mean horizontal velocity based on average flowrate (American Petroleum Institute, 1990).

The minimum total cross-sectional area of the separator (A_c) is given by:

$$A_c = \frac{Q_m}{VH} \quad \text{.............(13.4)}$$

where:

A_c = minimum total cross-sectional area of the separator, cm^2
Q_m = design effluent flowrate to the separator, cm^3/s
V_t = vertical velocity, cm/s

The number of separator channels required is given by:

$$n = \frac{A_c}{(150 \times 103)} \quad \text{.............(13.5)}$$

where:

A_c = minimum total cross-sectional area of the separator, cm^2
n = number of channels required

150 x 103 cm^2 is the maximum cross-sectional area (width = 610 cm; depth = 240 cm) recommended for a single channel (American Petroleum Institute, 1990).

The depth of the channel is given by:

$$d = \frac{A_c}{Bn} \quad \text{.............(13.6)}$$

where:

d = depth of channel, cm
A_c = minimum total cross-sectional area of the separator, cm^2
B = width of channel, cm
n = number of channels

The separator length is given by:

$$L = \frac{F V_H}{V_t} \quad \text{...........(13.7)}$$

where:

L = length of channel, cm
F = turbulence and short circuiting factor, dimensionless
V_H = mean horizontal velocity, cm/s
V_t = vertical velocity, cm/s
d = depth of channel, cm

The minimum horizontal area (A_H) is given by:

$$A_H = \frac{F\,Q_{m}}{V_t} \quad ....(13.8)$$

where:

A_H = minimum horizontal area, cm^2
F = turbulence and short circuiting factor, dimensionless
Q_m = effluent flowrate, cm^3/s
V_H = mean horizontal velocity, cm/s

13.3 Operation and Maintenance of Oil-Water Separators

The process design engineer shall identify and describe the operation and maintenance procedure for the oil-water separators.

CHAPTER 14: DESIGN OF DISSOLVED AIR FLOTATION

Dissolved air flotation (DAF) is commonly used to remove suspended solids and oil and grease from effluent streams via the use of air bubble flotation. DAF systems work exceptionally well in effluent streams that include solids that tend to remain in suspension or float such as food, chemical and petroleum based effluents. Sometimes chemical pretreatment is employed to help improve the performance of pollutant removal.

14.1 Design Criteria for Dissolved Air Flotation System

The design of DAF systems shall be based on the peak flowrate expected. Preferably the design is preceded by treatability testing, (jar testing or bench scale batch tests or on-site pilot tests) of effluent samples to determine the key design parameters which are commonly applied in the design of a DAF system such as air to solids ratio, chemical dosing, effluent quality, recycle rate, pressure, etc.

The design engineer shall identify, specify, incorporate and take into consideration the following design parameters/aspects:

- flowrate
- flow balancing or regulation
- effluent temperature
- effluent characteristics
- pH adjustment
- coagulation and flocculation pretreatment
- solids loading
- surface loading
- hydraulic loading
- air solids (AS) ratio
- solids handling system

Although the actual design values used are application specific, typical design criteria for sizing DAF systems for treating industrial effluents are given in Table 14.1.

Deviations from the above design criteria can be allowed if they can be substantiated by literature data or experimental data or data obtained from similar operations elsewhere.

Table 14.1: Design criteria for dissolved air flotation (DAF) system

Parameter	Unit	Set points
Recycle pressure	kPa	100 to 300
Air saturation efficiency	%	80 to 95

Table 14.1 continued

Recycle	%	15 to 50 for industrial effluents Up to 150 to 200 for activated sludge system
Pressurization tank detention time min	min	3
Hydraulic loading rate, feed only	$m^3/(m^2h)$	1.1 to 2.5
Hydraulic loading rate, including recycle	$m^3/(m^2h)$	2.5 to 3.6
Solids loading rate	$kg/(m^2h)$	2 to 15
Air-solids (AS) ratio at 20°C, 1 atm.	mL of air/mg of solids applied. kg air/kg solids applied	0.005 to 0.006 0.03 to 0.05
Detention time in flotation tank	min	20 to 60
Side water depth of the tanks	m	1.3 to 3.0

14.2 Design Methodology for Dissolved Air Flotation Systems

In a typical situation, a design exercise is preceded by laboratory tests using a flotation cell to yield pertinent design data such as plot of air to solids ratio versus effluent concentration and effluent concentration versus surface loading rate.

The design then proceeds as follows.
Typical design formulae used for the design of DAF systems are given below:

$$A/S = \frac{S_a R\,[(f\,P) - 1]}{S_o Q} \qquad \text{................(14.1)}$$

where:

- A/S = air to solids ratio, kg air kg solids or oil applied
- S_a = air solubility at atmospheric pressure, mg/L
- R = pressurized recycle, m^3/d
- f = percent air saturation in retention tank, typically ~ 0.85
- P = absolute pressure
- S_o = influent oil or suspended solids concentration, mg/L
- Q = influent flow, m^3/d

Note: P = (p gauge, kPa + 101.35)/101.35

Once the required A/S is determined from the experimental results, equation (14.1) is commonly used to determine the recycle rate (R).

The next step is to compute the surface area of the DAF's flotation tank required by using the formula:

$$A = \frac{Q + R}{SLR} \quad \ldots\ldots\ldots\ldots\ldots\ldots(14.2)$$

where:

A = surface are required, m^3
Q = influent flow, m^3/d
R = pressurized recycle, m^3/d
SLR = surface loading rate, $m^3/(m^2.d)$

The quantity of sludge generated inclusive of the sludge produced from the use of coagulants /flocculants shall then be computed.

The design engineer shall compile and document results from laboratory or pilot plant studies and all design calculations, and justify the design values selected in the design exercise.

14.3 Instrumentation for Process Control (Performance Monitoring)

The design engineer shall incorporate in the DAF design, appropriate instrumentation to monitor the perfomance of the DAF system. This may include the following:

- Flow meter
- pH meter
- Compressed air flow meter
- Turbidity meter, if deemed appropriate

For small flows and simple installations hand operated controls and manual flow control may be allowed but for bigger installations the DAF system shall be designed with programmable logic controllers (PLC), touch screen controls and automatic flow control. A fail-safe mode shall be provided to allow the DAF system to be operated manually in the event of a computer malfunction.

CHAPTER 15 - DESIGN OF ACTIVATED CARBON COLUMNS

Activated carbon adsorption has been widely as an advanced treatment technology to remove a variety of contaminants from industrial effluents. Activated carbon has an affinity for organics and its use for residual COD removal in Malaysian industries is not uncommon.

15.1 Design Criteria for Activated Carbon Adsorption Columns

Isotherm evaluation and pilot test usually precede a typical carbon adsorption design exercise to develop important design parameters, which may include adsorption isotherm constants, surface loading rate (SLR), nominal column diameter (D), and bed depth.

There are several approaches available for the design of adsorption columns. All established adsorption isotherm models and design approaches are acceptable. The engineer shall determine the breakthrough time (breakthrough adsorption capacity) of the carbon column by the use of the chosen adsorption isotherm model. Adsorption isotherms models in effluent treatment applications are typically represented via Freundlich or Bohart-Adams models. The design engineer is advised to refer to authoritative references such as Metcalf and Eddy (2003), and Eckenfelder, Ford and Englande (2008) for design examples.

The engineer shall determine the adsorber design details which may include the following:

- System operation whether:
  - Single or multiple units
  - downflow (fixed beds)
  - upflow (expanded beds)
  - continuous counter flow
- Temperature and pH of operation
- Granular or powdered activated carbon
- Effluent flowrate
- Surface loading rate
- Contact time
- Material of construction column
- Sampling ports
- Quantity of activated carbon required
- Empty bed contact time and number of columns used
- Column dimensions
- Overall system pressure drop
- Pretreatment requirements
- Contaminant concentration in influent and effluent

- Adsorbates competitive adsorption

15.2 Design Methodology for Carbon Adsorption Columns

Some useful commonly used formulae for the design of activated carbon columns are given below.

Column area is calculated from the formula:

$$A = Q/SLR \quad \text{...............(15.1)}$$

where:

A = column diameter, m^2
Q = effluent flowrate, m^3/d
SLR = surface loading rate, $m^3/(m^2.d)$

Breakthrough time is calculated from the relationship:

$$t_b = \frac{(x/m)_b M_c}{Q [C_i - (C_b/2)]} \quad \text{...............(15.2)}$$

where :

t_b = breakthrough time, d
$(x/m)_b$ = field breakthrough adsorption capacity, g/g
M_c = mass of activated carbon in the column, g
Q = effluent flowrate, m^3/d
C_i = influent pollutant concentration, mg/L
C_b = breakthrough or allowable pollutant concentration, mg/L

Using Boharts-Adams adsorption model, bed depth service time is calculated from the relationship:

$$t = \frac{N_o X}{C_o V} - \frac{1}{C_o K} \ln [(C_o/C_l) - 1] \quad \text{............(15.3)}$$

where:

t = bed service time, d
N_o = adsorptive capacity, mg of pollutant/L of carbon
X = depth of bed, m
C_o = influent pollutant concentration, mg/L
C_1 = breakthrough or allowable pollutant concentration, mg/L
V = linear flowrate, m/d
K = rate constant, L/(d.mg)

Overall column pressure shall be determined by using an appropriate formula, such as the one shown in equation (16.1).

15.3 Instrumentation for Process Control (Performance Monitoring)

The design engineer shall incorporate in the design, instrumentation system for the operation and monitoring of the perfomance of the activated carbon absorption column. This may include the following:

- Flow meters
- Pressure gages
- COD or TOC meter, if deemed appropriate

Methods of detecting breakthrough time (for example, column elapsed time or flow through or effluent quality) shall be clearly identified by the design engineer.

15.4 Carbon Regeneration

After the activated carbon column has reached exhaustion and all the active sites are filled, it can be regenerated by chemical regeneration or heating. If the design of adsorption column incorporates adsorbent regeneration, the design engineer shall specify the following:

- Chemical regeneration
  - chemical regeneration agents
- Thermal regeneration
- Regeneration
  - on-site offsite (to be perfomed by the vendor)

If the carbon adsorber will be regenerated off site or the spent adsorbent disposed off, the requirements on shipping and waste disposal requirements stipulated by the Scheduled Waste Regulations 2005 shall be complied with.

CHAPTER 16: DESIGN OF MEDIA FILTERS AND MEMBRANE PROCESSES

Media filtration and membrane filtration are commonly used to polish treated effluents to comply with stringent suspended solids discharge standards.

16.1 Design of Media Filters

The design engineer shall specify the following:

- mode of operation (continuous or intermittent)
- filter media (example: sand, granite, anthracite) and size
- filter bed depth
- flowrate (constant or variable)
- feeding method (pumping or gravity)
- backwash triger parameter (headloss or suspended solids concentration)
- operating pressure

The following hydraulic surface overflow rates are commonly used:

- gravity filters: 3.6 to 6.0 $m^3/(m^2.h)$
- pressure filters: 6.0 to 15.0 $m^3/(m^2.h)$

Assuming laminar flow conditions, the headloss per unit depth of sandfilter bed can be calculated by using the Blake-Kozeny equation as shown below:

$$H/L = \frac{(k/g)\nu V(1-\epsilon)^2(6/\psi d)^2}{\epsilon^3} \quad \text{........ (16.1)}$$

where:

H/L = headloss per unit depth, unitless
k = a constant, unitless (typical value, 5.0 for water filtration)
g = acceleration due to gravity (value, 9.81 m/s^2)
ν = dynamic viscosity, m^2/s
V = hydraulic surface overflow rate, m/s
ϵ = sand porosity factor, dimensionless
d = mean sand diameter, m

Backwash water shall be returned to the IETS to be retreated.

16.2 Design of Membrane Filtration Systems

The design engineer shall specify the following:

- Filter type and membrane pore size
- Operating pressure
- Membrane fouling preventive and corrective maintenance procedure

16.3 Instrumentation for Process Control (Performance Monitoring)

The engineer shall specify and incorporate appropriate instruments for monitoring the media filters or membrane filtration systems which may include flow meters, pressure gauges, temperature sensors and trans-membrane pressure gauges.

CHAPTER 17: DESIGN OF EVAPORATION SYSTEMS

Vacumm distillation which is a form of evaporation technique is sometimes used for treating and concentrating effluents from a wide range of industries and for the purpose of implementing zero discharge option.

17.1 Design of Vacumm Distillation Systems

The design engineer shall incorporate the following design and operational parameters in the design of vacumm distillation systems:

- pressure
- temperature
- use of anti foaming agents

The engineer shall explore the use of PLC and data logging features to enable the distillation column to run on automatic mode.

CHAPTER 18: DESIGN OF SLUDGE DEWATERING FACILITIES

Sludges produced from various unit operations and unit processes of industrial effluent treatment systems (IETSs) can be categorized primarily as scheduled wastes (typically chemical sludges) or non-scheduled wastes (typically biological sludges and other sludges). Commonly, these sludges are further treated through the use of a number of sludge dewatering techniques such as drying and filtration. The dewatering technologies commonly used in the industries in Malaysia are drying beds for biological sludges from sewage treatment systems and filter presses for chemical sludges from IETS. The purpose of these technologies is to reduce the volume and weight of the sludge which may contain appreciable amount of water.

18.1 Quantities of Sludge Generated

The quantities of sludge generated from each unit operation and unit process shall be estimated. For existing industries, results from jar test experiments shall be used in making the estimate.

The sizing of the sludge dewatering and storage facilities shall be based on the total sludge quantities generated.

18.2 Sizing of Sludge Dewatering Facilities

The design criteria shown in Table 18.1 shall be used for the design of thickener tanks.

Table 18.1: Design values for sludge thickener tanks

Design parameter	Units	Typical range
Solids loading rate	kg/(m^2 .d)	80 to 180
Surface overflow rate	m3/(m^2 .d)	22

18.3 Plate and Frame Pressure Filtration Systems (Filter Presses)

The most widely used technology for dewatering chemical sludges is the filter press. The design engineer shall design the filter press adequately to handle the expected sludge quantity produced, by exploring or taking into consideration the following aspects, wherever relevant:

- automatic operation of the filter press
- low pressure or high pressure operation; design pressure (kPa)
- equalization and feed tanks
- PLC control and automation
- Chemical conditioning
- loading (kg/d)

- sludge concentration, (%)
- cake density, (kg/m^3)
- number of filter cycles per day
- use of conveyors, drip trays, piping and plate shifters (manual), semi-automatic or fully automatic operation
- filtrate treatment
- method of cake disposal (hopper, drum, conveyor)
- filter dimensions
- filter cake storage

18.4 Belt Pressure Systems (Belt Presses)

The design engineer shall take into consideration and provide information on the following:

- belt size
- SS content (%)
- cake solids (%)
- coagulant and flocculant addition (dose)
- hydraulic loading rate ($m^3/(m^2.h)$
- solids loading rate (total dry solids) ($kg/(m^2.h)$)

18.5 Dryers

Some industries generating small qualities of sludge utilize evaporation techniques for removing moisture from the IETS sludge. Steam is typically used as the heat source. Sludge dryers shall be used only for drying sludges which have not been contaminated with volatile organic compounds (VOCs) such as those from printing operations using water-based inks. The engineer shall ensure the temperature of operation does not exceed the volatilization temperature of the most volatile VOC contained in the sludge (note: water-based inks do contain small amounts of VOCs). When designing such a dryer system, the engineer shall take into consideration or explore the following aspects:

- characteristics of the sludge including the volatile organic compounds, if applicable
- quantity of sludge produced
- volatilization of the components found in the sludge
- installation of temperature measuring devices and recording device to continuously monitor and record the temperature of the dryer
- installation of air pollution control system, where applicable.

18.6 Open Sand Beds

Open conventional sludge drying beds for drying biological sludges from industrial effluent treatment systems are not recommended. Separation distance requirements to avoid odor nuisance to immediate neighbors and inclement weather conditions restricting their use in certain seasons of the year are factors which discourage their use in Malaysia.

18.7 Filtrate

All filtrate generated from sludge dewatering processes shall be returned to the IETS to be retreated.

18.8 Sludge Cake Disposal

The design engineer shall state clearly the preferred option for final method of disposal of the sludge cake produced from the dewatering or drying process. All applicable regulations such as the Scheduled Waste Regulations 2005 for the management of scheduled wastes shall be complied with.

18.9 Instrumentation for Process Control (Performance Monitoring)

Appropriate instrumentation and controls shall be incorporated in the design of all sludge dewatering systems.

CHAPTER 19: DESIGN OF INSTRUMENTATION, CONTROL AND ELECTRICAL SYSTEM

An integral part of the design of an industrial effluent system (IETS) is the design of instrumentation, control and electrical system. The design of instrumentation, control and electrical systems shall conform to applicable Acts, Codes and Regulations including:

- Electricity Supply Act 1990,
- National Electrical Safety Code 1994, and
- Occupational Safety and Health Act 1994.

The design of the electrical or electronics components of the IETS shall be carried by an electrical engineer or electronic engineer, respectively.

The design engineers shall obtain the necessary approvals required in connection with the design, installation and operation of the equipment or systems regulated by the applicable Acts, Codes and Regulations.

In addition to the instrumentation requirement which has been specified in the individual chapters of this document, the design engineer shall identify appropriate instruments and on-line sensors that would enhance the monitoring of key IETS process parameters and hence result in better operational control of the IETS. Whenever deemed appropriate, the engineer in consultation with the industry owner shall incorporate such instruments in the design of the IETS.

19.1 Instrumentation and Control Systems Requirements

19.1.1 Operational Reliability

All instruments and control systems shall be designed with both operational reliability (accurate and repeatable results) and maintainability to ensure smooth and effective operation of the IETS.

19.1.2 Back-up Equipment

Instrumentation whose failure could result in effluent by passing or a violation of the effluent discharge standards shall be provided with an installed back up sensor and read out.

An automatic instrumentation system shall be backed up by an alternative manual system so that the IETS operation is not affected while the malfunctioned instrument is undergoing repair.

19.1.3 Calibrations

Vital instrumentation and control equipment shall be designed to permit alignment and calibration without requiring by passing of effluent or a violation of the effluent discharge standards. Automated systems shall have provisions for operator verification of performance and all necessary systems calibration devices.

19.1.4 Alarms and Annunciators

Alarms and annunciators shall be provided to monitor the condition of equipment failure where the failure could result in effluent by passing or a violation of the effluent discharge standards. Where ever appropriate, alarms and annunciators shall also be provided to monitor violation of effluent standards at the final discharge point.

19.1.5 Spare Components

An adequate number of spare components shall be specified by the design engineer to permit in-plant repairs or modifications and adjustment. These include a variety of components such as starters, low voltage contactors, and components subject to wear and tear, such as motor brushes and switches. The design engineer shall also specify spare equipment components required for IETS performance monitoring such as pH meters, ORP meters and dissolved oxygen meters etc. and other instruments necessary for the smooth operation of the IETS such as dosing equipment, aeration system, etc.

CHAPTER 20: DESIGN OF MECHANICAL COMPONENTS

Mechanical components in an IETS include pumps, piping system, valves, fittings, brackets supports, pressure gages etc. Preferably, the design of these IETS components shall be undertaken by a mechanical engineer, although a chemical engineer who has been involved in similar design exercises would be perfectly acceptable. The general design criteria to be used in designing the IETS mechanical components and choice of materials shall conform to sound engineering practices applicable to the field of industrial effluent engineering practiced world-wide.

CHAPTER 21: IETS MAINTENANCE PLAN

The engineers involved in the design of the treatment processes, mechanical, and electrical systems shall prepare a preventive maintenance management plan to ensure the installed systems, components, and units are properly maintained throughout the service life of the IETS. The maintenance plan involves the monitoring of the mechanical, electrical systems, chemical tanks and stores, and other ancillary equipment. The preventive maintenance plan shall be categorized into daily, weekly, monthly, and yearly program that may include the maintenance of the following components/equipment: pumps, stirrers/mixers, tanks, pipes, air compressors, air blowers, aerators, motors, control panel elements, and float switches. The maintenance program may involve the following activities: checking of the motor amperages and voltages, checking of pipe leakages, checking of levels of chemicals in storage tanks, inspection of conditions of chemical tanks, repaint of mechanical elements, cleaning of filters, replacement of spent adsorbents, etc.

CHAPTER 22: FINAL DISCHARGE POINT

There shall be only one discharge point from the entire premise. An exception for this rule is described in the following paragraph. The discharge point shall be the point where the treated effluent is discharged after the last unit process or unit operation of the IETS. A flow meter and totalizer shall be installed at the final discharge point. Additionally, the engineer shall explore the need and practicality to monitor on a continuous basis, other relevant parameters which are amenable to on-line measurement, such as pH, COD (or TOC, in place of COD), ammonia and suspended solids . In certain cases, the suitability of incorporating a bioassay assessment facility to monitor the whole effluent toxicity (WET) shall also be considered.

Wherever appropriate, the IETS design shall incorporate provision for rerouting non-compliant effluent to storage tanks (sometimes known as "off-spec" tanks) for temporary storage, before corrective actions are instituted to address the non compliance issue.

A premise may be allowed to have another discharge point if it has a raw materials storage yard which is not roofed, hence exposed to rain. The owner and design engineer shall provide evidence maintaining an uncovered raw materials yard is the industry best practice for that industry. If deemed appropriate, the run off from the yard may be collected and treated separately and finally discharged through another discharge point. The requirement on discharge monitoring and reporting also applies to this discharge point.

For the purpose of completeness and ease of reference, the specifications on the final discharge point stipulated in Eleventh Schedule of the Industrial Effluent Regulations 2009 (IER) are reproduced in table 21.1. The specifications are relevant to the design of the IETS, hence shall be complied with.

Table 21.1: Eleventh Schedule to the Industrial Effluent Regulations, 2009

Eleventh Schedule

[Subregulation 17(1)]

SPECIFICATIONS OF POINT OF DISHARGE OF INDUSTRIAL EFFLUENT OR MIXED EFFLUENT

1. The discharge point is located within the boundary of the premises, immediately after the final unit operation or unit process of the industrial effluent treatment system.
2. The location of the discharge point is easily accessible and does not pose any safety hazards to personnel performing site inspection or effluent sampling.
3. The industrial effluent or mixed effluent is discharged through a pipe, conduit or channel to facilitate effluent sampling.
4. The discharge point is physically identified by installing a metal identification sign which reads "Final Discharge Point".
5. The discharge point and its surrounding is properly maintained to be free from any obstruction that may pose difficulty or hazards during site inspection or effluent sampling.

IMPORTANT NOTICE

The criteria specified in this Guidance Document represent the minimum requirements for the design and operation of Industrial Effluent Treatment Systems (IETSs) to be complied with by the industries. However, the Department of Environment (DOE) assumes no responsibility for the accuracy, adequacy, or completeness of the concepts, methodologies, or protocols described in this document. The owner shall secure competent advice and the designer shall take additional measures where deemed appropriate, to further ensure compliance with the effluent discharge standards stipulated in the Industrial Effluent Regulations 2009 and other requirements set out in other Acts or regulations. Compliance with the regulatory requirements and standards is solely the responsibility of the industries.

This Guidance Document was authored by Ir. Dr. Shamsudin Ab. Latif, former Deputy Director General (Development), DOE. The Sixth Edition of this Guidance Document was approved by the Certification Committee chaired by Dato' Dr. Ahmad Kamarulnajuib Che Ibrahim, Deputy Director General (Development), DOE.

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