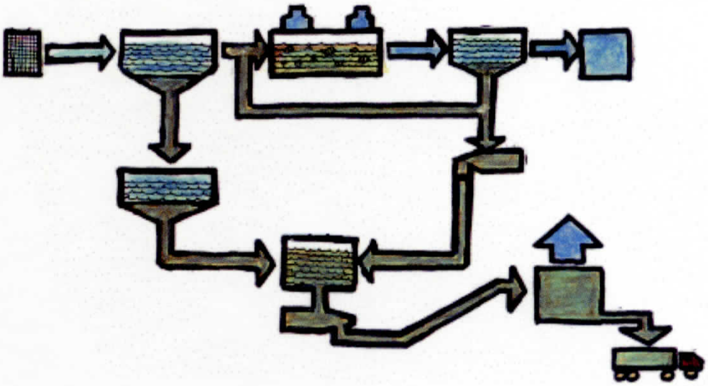
A GUIDEBOOK ON PERFORMANCE MONITORING

FOR INDUSTRIAL EFFLUENT TREATMENT SYSTEM OPERATORS

First Edition



ENVIRONMENT INSTITUTE OF MALAYSIA (EiMAS)
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MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT
UNIVERSITI KEBANGSAAN MALAYSIA CAMPUS
LOCKED BAG NO. 24, 43600, UKM BANGI
SELANGOR, MALAYSIA
TEL: +603-89261500 FAX: +603-89261700
WEBSITE: http://www.doe.gov.my/eimas

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LIST OF ABBREVIATIONS

AS	Activated sludge
AL	Aerated lagoon
AN	Ammoniacal nitrogen
BOD	Biochemical oxygen demand
BP	Biological process
COD	Chemical oxygen demand
DO	Dissolved oxygen
EAAS	Extended aeration activated sludge
EQ	Equalization tank
EQA	Environmental Quality Act 1974
F/M	Food to microorganism
FTR	Field training report
HRT	Hydraulic retention time
IECS	Industrial effluent characterization study
IER	Industrial Effluent Regulations 2009
IETS	Industrial effluent treatment systems
MBR	Membrane bioreactor
MDMR	Monthly discharge monitoring report
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
OD	Oxidation ditch
OP	Oxidation pond
ORP	Oxidation reduction potential
OUR	Oxygen uptake rate
O&G	Oil and grease
PCP	Physical-chemical processes
RAS	Return activated sludge

RBC	Rotating biological contactor
SBR	Sequencing or sequential batch reactor
SI	Solids inventory
SOUR	Specific oxygen uptake rate
SS	Suspended solids
SSV	Settled sludge volume
SVI	Sludge volume index
TF	Trickling filter
UASB	Upflow anaerobic sludge blanket
VSS	Volatile suspended solids
WAS	Waste activated sludge
ZSV	Zone settling velocity

PART I INTRODUCTION

1.0 INTRODUCTION

Industrial effluents vary significantly in pollution characteristics hence different **unit processes** and **unit operations** are utilized to treat them. This guidebook presents general guidelines and considerations on performance monitoring requirements so that effective monitoring program can be established for the varied unit processes and operations in an industrial effluent treatment system (IETS).

Eventhough some industries are routinely conducting various tests to monitor the performance of the unit operations and unit processes which make up the effluent treatment system in their premises, by and large, the practice of **performance monitoring** of industrial effluent treatment system in many industries is an exception rather than the norm. Performance monitoring can be understood to mean the following:

(i) **Preventive** or **routine maintenance** is "an orderly program of positive actions (equipment cleaning, adjustments and/ or testing, lubricating, reconditioning) for preventing failure of monitoring parts and systems during their use".

(ii) Failure of system or part of system calls for **corrective maintenance** (non routine maintenance).

Table 1.1: Common treatment technology and applicable course for the IETS operators

Process	Common Technology	Process Classification	Applicable Cours
Suspended growth process	Conventional activated sludge (CAS)	BP	CePIETSO (BP)
	Extended aeration activated sludge (EAAS)	BP	CePIETSO (BP)
	Sequencing batch reactor (SBR)	BP	CePIETSO (BP)
	Oxidation ditch (OD)	BP	CePIETSO (BP)
	Upflow anaerobic sludge blanket (UASB)	BP	CePIETSO (BP)
Fixed film process	Trickling filter (TF)	BP	CePIETSO (BP)
	Rotating biological contactor (RBC)	BP	CePIETSO (BP)
Pond processes	Anaerobic lagoon/pond Facultative pond Stabilization pond	BP BP BP	CePIETSO (BP)
Sedimentation/ clarification (gravity separation)	Sedimentation tank/ clarifier	PCP	CePIETSO (PCP)
Equalization	Equalization tank (EQ)	PCP	CePIETSO (PCP)

Process	Common Technology	Process Classification	Applicable Cours
Flotation	Dissolved air flotation (DAF)	PCP	CePIETSO (PCP)
Precipitation of suspended solids	Coagulation and flocculation	PCP	CePIETSO (PCP)
Ion exchange	Ion exchange column	PCP	CePIETSO (PCP)
Chemical precipitation	Metal hydroxide precipitation; Metal carbonate precipitation; Other precipitation technologies	PCP	CePIETSO (PCP)
Redox reaction	Two stage chromium removal	PCP	CePIETSO (PCP)
Chemical oxidation	Alkaline chlorination for cyanide removal	PCP	CePIETSO (PCP)
Membrane processes	Reverse osmosis	PCP	CePIETSO (PCP)
	Ultrafiltration	PCP	CePIETSO (PCP)
	Electrodyalisis	PCP	CePIETSO (PCP)
Oil deemulsification	Acidification; chemical addition	PCP	CePIETSO (PCP)
Metal deposition	Electrowinning	PCP	CePIETSO (PCP)

Process	Common Technology	Process Classification	Applicable Cours
Gravity separation	Corrugated plate clarifier (CPI), American Plate Interceptor (API)	PCP	CePIETSO (PCP)
	Lamella plate clarifier	PCP	CePIETSO (PCP)
Advanced oxidation process	Fenton process	PCP	CePIETSO (PCP)
Evaporation	Vacuum distillation	PCP	CePIETSO (PCP)

Note: BP = Biological Process; PCP = Physical-Chemical Process. List of process and technology is not exhaustive

1.1 Effluent discharge standards

The main provision dictating the quality of **final effluents** to be complied with is **Regulation 11**, while the designated discharge standards for all regulated parameters with the exception of COD are prescribed in the **Fifth Schedule**. **Regulation 12** stipulates the COD standards which are prescribed in the **Seventh Schedule**. COD standards are set according to the **industry categories** (commonly known as **sectoral standards**). Both schedules are reproduced below. **Standard A** applies to sources which discharge into a watercourse where there is a **water abstraction point** downstream of the discharge point, while **Standard B** applies to sources whose discharge point is downstream of water abstraction points.

THIRD SCHEDULE

[Regulation 11(1), 11(2), 11(3)]

PARAMETER LIMITS OF EFFLUENT OF STANDARDS A AND B

	Parameter (1)	Unit (2)	Standard (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	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	0.50
(xxii)	Barium	mg/L	1.0	2.0
(xxiii)	Fluoride	mg/L	2.0	5.0
(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	0.5	0.5
(xxviii)	Oil and Grease	mg/L	1.0	10.0
(xxix)	Ammoniacal nitrogen	mg/L	10	20
(xxx)	Color	ADMI	100	200

SEVENTH SCHEDULE

(Regulation 12)

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

(1) Trade/Industry	(2) Unit	(3) Standard A	(4) Standard 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	mg/L	400	400
(d) Other industries	mg/L	80	200

Table 1.2: Priority effluent parameters for different industries*

Industry Type	Typical Priority Effluent Parameters
Chlor-Alkali (Mercury Cell)	T, pH, SS, Mercury, Chlorides
Chlor-Alkali (Diaphragm Cell)	T, pH, SS, Chlorides
Metal Finishing and Electroplating	T, pH, SS, O&G, Arsenic, Cadmium, Chromium (trivalent), Chromium (hexavalent), Lead, Nickel, Mercury, Silver, Zinc, Fluoride, Cyanides-depending on the metals involved
Fertilizer (Nitrogenous)	T, pH, COD, SS, AN
Fertilizer (Phosphate)	T, pH, COD, SS, AN, Fluoride
Pulp and Paper	T, pH, BOD_5, COD, SS, Sulfides,
Petroleum Refining	T, pH, COD, SS, BOD_5, O&G, Phenolic compounds
Steel Industry	T, pH, COD, SS, Chromium (trivalent), Iron, Cadmium, Copper, O&G, Fluoride
Synthetic Fiber	T, pH, BOD_5, COD, SS, Sulfides, O&G
Tanning and Leather Finishing	T, pH, BOD_5, COD, SS, Sulfide, Chromium (trivalent), Chromium (hexavalent), Phenolic compounds, O&G,
Textile Processing	T, pH, BOD_5, COD, SS, Chromium, Copper, Color
Pigments and Dyes	T, pH, COD, Lead, Copper, Zinc
Thermal Power Plants	T, pH, SS, O&G
Rubber Products	BOD_5, COD, SS, Zinc, Chromium,
Paints, Varnishes & Lacquers	pH, COD, SS, Lead, Chromium, Cadmium, Zinc, Barium
Pesticides	pH, COD, Mercury
Printing	COD, Lead, Color
Industrial Chemicals	pH, BOD_5, COD, SS Phenolic Compounds, Cyanide, AN, Cadmium, Lead, Chromium, Mercury, Nickel, Zinc, Arsenic
Oil & Gas Production	T, pH, BOD_5, COD, SS, O&G, Chloride, Phenolic Compounds, AN, Fluorides, Barium, Boron, Formaldehyde
Petrochemicals	T, pH, BOD_5, COD, SS, O&G, Phenolic Compounds
Dairy Industry	T, pH, BOD_5, COD, SS, O&G
Fruit and Vegetable Processing	T, pH, BOD_5, COD, SS
Food and Beverage	T, pH, BOD_5, COD, SS, O&G
Glass Manufacturing	T, pH, COD, SS, Barium, O&G
Sugar	T, pH, BOD_5, COD, SS, O&G
Detergent	pH, COD, O&G, Anionic Detergent
Photographic	pH, COD, Silver, Cyanide, Fluoride
Glue Manufacture	pH, BOD_5, COD, Phenolic compounds; Formaldehyde
Oil & Gas Exploration	T, pH, BOD_5, COD, SS, O&G, Chloride, Phenolic compounds, Boron, Fluoride, AN
Vegetable Oil Mills	T, pH, BOD_5, COD, SS, O&G
Plastic Materials and Products	SS
Wood Products	pH, SS, COD, Phenolic compounds
Pharmaceutical	T, pH, BOD_5, COD, SS
Solar panel	T, pH, COD, Fluoride, AN

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

Table 1.3: Treatment technology selection matrix

Type of Pollutant	Type of Treatment Process
a) Degradable organics (reflected in BOD level)	Biological treatment - Stabilization ponds - Aerated lagoons - Trickling filters (TFs) - Rotating biological contactors (RBCs) - Activated sludge (AS) - Anaerobic treatment
b) Volatile organics	Biological treatment Air or steam stripping Carbon adsorption Chemical oxidation
c) Refractory toxic organics (reflected in COD level)	Carbon adsorption Chemical oxidation Anaerobic treatment Wet air oxidation
d) Suspended solids	Sedimentation Flotation Filtration Membrane processes
e) Oil and grease	Gravity separation - Oil trap - Corrugated plate interceptor (CPI) - American Petroleum Institute (API) separator Flotation
f) Metals	Chemical precipitation Ion exchange
g) Nutrients-Nitrogen	Steam stripping Biological treatment - Nitrification & denitrification
h) Nutrients-Phosphorus	Chemical precipitation Biological treatment
i) Color	Carbon adsorption Chemical oxidation

Table 1.4: Classification of effluent treatment processes

Classification of Treatment	Treatment Process
Primary (preliminary, pretreatment)	Equalization Neutralization Flotation Sedimentation Coagulation/flocculation Chemical precipitation Ion exchange Filtration Adsorption Air stripping
Secondary (Biological treatment)	Biological oxidation - activated sludge (AS) - trickling filter (TF) - rotating biological contactor (RBC) - oxidation pond (OP) - aerated lagoon (AL) - upflow anaerobic sludge blanket (UASB)
Tertiary (Advanced treatment)	Adsorption Ion exchange Biological nitrogen removal Chemical precipitation for phosphorus removal Media filtration Membrane processes Chemical oxidation

PART II PERFORMANCE MONITORING OF COMMON BIOLOGICAL TREATMENT PROCESSES

2.0 PERFORMANCE MONITORING OF COMMON BIOLOGICAL TREATMENT PROCESSES

Table 2.1: Typical operational parameters of EAAS and CAS (Source: USEPA, 1999)

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

Table 2.2: Key design and operational parameters for a SBR operating with conventional load (Source: AquaSBR Design Manual, 1995)

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

Table 2.3: Typical MLSS concentration for different types of AS system

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

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

pH

(i) Microorganisms work best within certain pH range (optimal range: 6.5 - 8.5); hence this pH range needs to be monitored and maintained.

(ii) Most IETS will have concrete structures which are susceptible to corrosion if exposed to extreme pHs.

Table 2.4: Typical range of SOUR values for different situations of microbial growth

SOUR, mgO_2/h / gMLVSS	Nature of microbial growth/ microorganism involved	Floc description, settling characteristic
> 20	Logarithmic growth/ Flagellates	Dispersed floc; Settling Slow
12-20	Declining growth/ Ciliates	Flocs forming; Settling normal
< 12	Endogenous respiration/ Rotifers and higher life	Pin floc; Settling fast

Table 2.5: Guide on sludge volume index and sludge settling property

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

Table 2.6: Typical F/M ratios for different types of AS system

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

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

Table 2.7: Typical sludge age (θ_c) for different types of AS system

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

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

Table 2.8: The roles played by different types of microorganisms

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

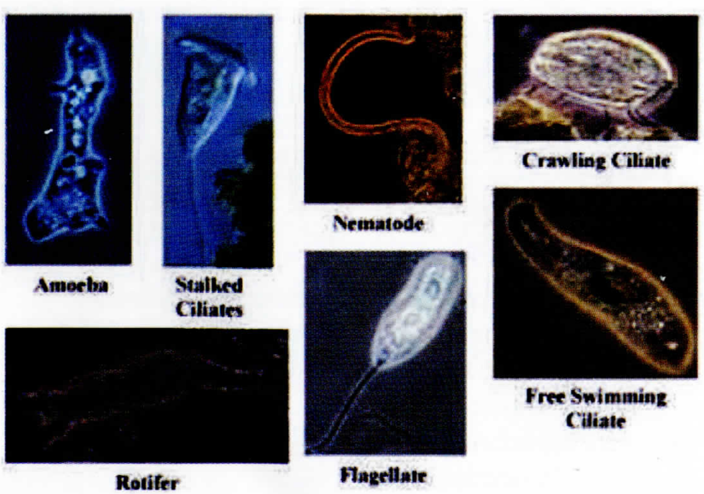

Figure 2.1: *Common indicator organisms one would see when looking under a microscope at a sample of activated sludge (Source : http://water.me.vccs.edu)*

Table 2.9: Typical biochemical processes, reactions in IETS BPs and corresponding ORP

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

Note: ** typically, more relevant to sewage treatment*

Table 2.10: Relevant PM parameters for different BPs

BP type	Relevant Parameters
CAS, EAAS,	Flowrate, pH, DO, F/M, OUR, SOUR, sludge age, Nutrients; MLSS, MLVSS, microscopic microorganism examination
SBR	Flowrate, pH, DO, F/M, OUR, SOUR, sludge age, Nutrients; MLSS, MLVSS, microscopic microorganism examination
UASB	Flowrate, VFA, alkalinity, pH, BOD, COD, SS, VSS, ZSV, ORP, SVI, Biogas Production
TF	Flowrate, pH, BOD, COD, DO,
RBC	Flowrate, pH, BOD, COD, DO,
Anaerobic ponding system	Flowrate, BOD, COD, VFA, alkalinity, pH, sludge depth
Aerobic ponding system	Flowrate, pH, BOD, COD, DO, sludge depth

Table 2.11: Summary of methods to control an activated sludge process

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

Control method	Information and data required	Details of operator's task for controlling the activated sludge process using the
Sludge age (θ_C)	• By trial and error determine the optimum sludge age which gives the best quality of final effluent. • Data required: MLVSS in the aeration tank : kg VSS in waste sludge/d : kg VSS in effluent/d $\theta_C,d = \frac{kg\ MLVSS_{in\ the\ aeration\ tank}}{[kg\ VSS_{in\ waste\ sludge}/d] + [kg\ VSS_{in\ effluent}/d]}$	• Change sludge age by increasing or decreasing the amount of sludge wasted.
Microbiology	• Daily observation of the number of stalked or free swimming ciliates or the presence of rotifers.	• If there is a decrease in the number of free swimming ciliates and a corresponding increase in the number of stalked ciliates, lower the solids level by increasing sludge wasting.

Control method	Information and data required	Details of operator's task for controlling the activated sludge process using the
Sludge Volume Index (SVI)	• Determine the optimum SVI which gives the required effluent quality • Information required: Settled sludge volume (SSV), mL/L; and MLSS, mg/L $SVI = \frac{SSV,\ mL/L \times 1000}{MLSS\ concentration,\ mg/L}$	• If SVI is increasing, increase the solids level and sludge age by lowering the sludge wasting rate. • If SVI is decreasing, Decrease the sludge age by wasting more.
Specific oxygen uptake rate (SOUR)	• Information required: OUR and MLVSS • Optimum range of SOUR: is 8 to 20 mg of O_2 per hour per g of MLVSS SOUR= OUR/MLVSS	• If SOUR > 20 mg of O_2 per liter per hour per g MLVSS, increase the aeration time. On a longer time, increase the sludge age and MLVSS by decreasing sludge wasting and increasing the rate of sludge return. • If SOUR < 8 mg O_2 per hour per g MLVSS, increase the wasting rate.

Table 2.12: Performance Monitoring Testing Guide for Biological Treatment Processes

Parameter	Sample location	Sample type	Sampling frequency
Equalization tank			
Flow	Effluent	Totalizer	Daily
BOD_5	Effluent	Preferably composite	Weekly
COD	Effluent	Preferable composite	Daily
pH	Effluent	In-situ	Daily
TIN	Effluent	Grab	Monthly
Aeration tank			
DO	Aeration tank, preferably at three locations	In-situ	Daily
MLSS	Effluent	Grab	Daily
MLVSS (from MLSS analysis)	Effluent	Grab	Weekly
SVI	Effluent	Grab	Daily
pH	Aeration tank	In-situ	Daily
SS of RAS	RAS line	Grab	Daily
SS of WAS	WAS line	Grab	Daily
QRAS	RAS line	Totalizer	Daily
QWAS	WAS line	Totalizer	Daily
F/M ratio	-	-	Weekly
SOUR	Aeration tank at effluent end	Grab	Weekly
Microscopic examination	Effluent	Grab	Weekly
Secondary clarifier			
Sludge level/blanket	Middle of clarifier	Grab	Daily or several times daily
BOD_5	Effluent	Preferably composite	Weekly
COD	Effluent	Preferably composite	Daily
SS	Effluent	Preferably composite	Daily
pH	Effluent	In-situ	Daily
TIN	Effluent	Grab	Monthly

PART III PERFORMANCE MONITORING OF COMMON PHYSICAL CHEMICAL TREATMENT PROCESSES

3.0 PERFORMANCE MONITORING OF COMMON PHYSICAL CHEMICAL TREATMENT PROCESSES

Performance monitoring of the following physical chemical treatment processes commonly used for the treatment of industrial effluents will be discussed: **neutralization and pH adjustment, chemical precipitation, coagulation, flocculation, flotation, two stage chromium treatment, alkaline chlorination for cyanide removal, ion exchange, activated carbon adsorption, media filtration, membrane filtration, and evaporation technique (vacuum distillation).**

3.1 Performance monitoring of neutralization and pH adjustment process

Performance monitoring activity centers around the following tasks:

(i) Maintaining and calibrating the **pH meter** as per manufacturer's manual

(ii) Ensuring sufficient supply of **neutralizing agent** in the storage tank

(iii) Conducting **titration experiments** to determine/verify the amount of chemical needed and to calibrate the automatic instrumentation system or determine/adjust the correct setting of the dosing pump.

(iv) Ensuring the **desired pH** level is maintained at all time.

3.2 Performance monitoring of metal precipitation process

Performance monitoring routine will revolve around the same activities as in the case of monitoring neutralization/pH adjustment process, namely:

(i) Maintaining and calibrating the **pH meter** as per manufacturer's manual
(ii) Ensuring sufficient supply of **precipitating agent** in the storage tank
(iii) Conducting **jar test experiments** to determine/verify the amount of chemical needed and to calibrate the automatic instrumentation system or determine/adjust the correct setting of the dosing pump.
(iv) Monitoring and ensuring the **desired pH** level is maintained at all time.
(v) Monitoring the **metal concentration** in the influent to the precipitation tank and effluent from the tank/clarifier.

3.3 Performance monitoring of two stage chromium removal process

Performance monitoring routine will concentrate on such activities as:

(i) Maintaining and calibrating the **pH and ORP meters** as per manufacturer's manual
(ii) Ensuring **sufficient supply** of acid, reducing and alkaline agents in the storage tank
(iii) Calibrating/adjusting the correct **setting** of the dosing pumps.
(iv) Monitoring and ensuring the **desired pH and ORP** levels are maintained at all time.
(v) Monitoring the **chromium concentration** in the influent to the precipitation tank and effluent from the tank/clarifier.

Table 3.1: Performance Monitoring for two stage chromium removal process

Stages	Key Parameter	Recommended Range	Process Involved
First stage	pH	Between 2 and 3	The reduction of chromium (6+) to chromium (3+)
	ORP	at + 250 mV and above	
Second stage	pH	Between 8 and 9	Precipitation of chromium (3+) as chromium hydroxide.

3.4 Performance monitoring of alkaline chlorination for cyanide removal process

The monitoring of alkaline chlorination for cyanide removal process includes:

(i) Maintaining and calibrating the **pH and ORP meters** as per manufacturer's manual

(ii) Ensuring sufficient **supply of hypochlorite** solution and alkaline agent in the storage tank

(iii) Calibrating/adjusting the correct **setting** of the dosing pumps.

(iv) Monitoring and ensuring the **desired pH and ORP** levels are maintained at all time.

(v) Monitoring the **cyanide concentration** in the influent to and effluent from the chlorination tank.

Table 3.2: Performance Monitoring for cyanide removal process

Stages	Key Parameter	Recommended Range	Process Involved
First stage	pH	at 11 or above	Cyanide is converted to cyanate
	ORP	Between 325 mV and 400 mV	
Second stage	pH	at about 8.5	The cyanate is oxidized to carbon dioxide
	ORP	Between 600 mV to 800 mV	

3.5 Performance monitoring of ion exchange process

The monitoring of the ion exchange process consists of the following:

(i) Maintaining and calibrating the **pH meter** as per manufacturer's manual

(ii) Monitoring the **pH of the influent** to the column

(iii) Monitoring the onset of breakthrough time either in the form of monitoring the **volumetric throughput, column usage time** or **effluent quality** (metal concentration)

(iv) Monitoring **effluent** conductance and /or pressure in the inlet and outlet of the column.

(v) The disposal or regeneration of **used ion exchange resins** needs to be managed in accordance with the requirements stipulated in the Scheduled Waste Regulations 2005.

3.6 Performance monitoring of activated carbon adsorption column

The monitoring of the carbon column consists of:

(i) Monitoring the onset of breakthrough time either in the form of monitoring the **volumetric throughput, column usage time** or **effluent quality** (for example COD).

(ii) The disposal or regeneration of **used activated carbon** needs to be managed in accordance with the requirements laid down in the Scheduled Waste Regulations 2005.

3.7 Performance monitoring of coagulation and flocculation processes

The performance monitoring tasks of the IETS supervisor or operator includes the following:

(i) Observe **floc formation** on a routine basis and ensure that both the coagulation and flocculation processes happen satisfactorily

(ii) Conduct **jar test experiments** to determine/verify the amount of coagulant and flocculant needed and calibrate/adjust the correct setting of the dosing pump.

(iii) Monitor and ensure the **desired pH** is maintained at all time

(iv) Maintain and calibrate the **pH meter** as per manufacturer's manual

(v) Ensure sufficient **supply of coagulant and flocculant** in the storage tank

3.8 Performance monitoring of dissolved air flotation process

The performance monitoring of DAF process involves the following tasks:

(i) Monitor **flowrate** of the inlet and recycle streams

(ii) Monitor **suspended solids** (SS) or **oil and grease** (O&G) concentration in the inlet stream

(iii) Monitor **operating pressure**

(iv) Observe/monitor **speed** of the skimmer

Table 3.3: Performance Monitoring for dissolvedair flotation process

Key Parameter	Recommended Range
A/S ratio	0.03 to 0.05 (by weight).

3.9 Performance monitoring of media filtration

Performance monitoring tasks for media filters involves the following:

(i) **Flowrate**

(ii) Monitor **differential pressure** between the upstream and downstream side of the filter

(iii) Ensure **backwashing** process works properly.

(iv) Periodic **washing of filters** is necessary for removal of **accumulated solids**.

3.10 Performance monitoring of membrane filtration

Performance monitoring of membrane filters is typically carried out by continuous monitoring the following operational parameters:

(i) **Flow** of the feed, filtrate and concentrate stream
(ii) **Pressure** of the feed, filtrate and concentrate stream
(iii) **Elapsed run time**
(iv) **Temperature** of the feed and filtrate
(v) **Flux**
(vi) **Recovery**
(vii) Trans-membrane **pressure** and specific ultrafiltration **resistance** (SUR) for UF filters.

3.11 Performance monitoring of evaporation techniques

Performance monitoring of mechanical evaporators including vacuum distillation systems involves continuous monitoring of the following:

(i) **Conductivity** of the process distillate.
(ii) **Vacuum pressure**
(iii) **Temperature**

Table 3.4: Performance Monitoring Testing Guide for Physical Chemical Treatment Processes

Process	Test/Check	Frequency	Remarks
Chemical Precipitation	Flowrate	Daily	
	pH	Daily	
	Chemical dosage system	Daily	- To calculate the chemical dosage - To ensure it's working properly
	Metals (if process is for metals removal)	Daily	Influent & effluent

Process	Test/Check	Frequency	Remarks
Oxidation/ Reduction	Flowrate	Daily	
	pH	Daily	
	ORP	Daily	
	Chemical dosage system	Daily	- To calculate the chemical dosage - To ensure it's working properly
	Metals	Daily	Influent & effluent
	COD, if relevant	Daily	Influent & effluent
Dissolved Air Flotation (DAF)	Recirculation flowrate	Daily	
	Pressure	Daily	
	Air flowrate	Daily	

Process	Test/Check	Frequency	Remarks
Ion Exchange	Flowrate	Daily	
	Metals (the relevant ones)	Weekly or daily; more frequent as breakthrough is approached	Influent & effluent
	Pressure difference	Daily	
Electrowinning	Flowrate	Daily	
	Current	Daily	
	Voltage	Daily	
	pH	Daily	
	Temperature	Daily	
	Metal (the relevant one)	Per batch (if batch process)	Influent & effluent

Process	Test/Check	Frequency	Remarks
Carbon Adsorption	Flowrate	Daily	
	Contaminant to be removed (e.g. COD)	Daily; more frequent as breakthrough is approached	Influent & effluent
	Pressure difference	Daily	

PART IV TROUBLESHOOTING

4.0 TYPICAL UPSET CONDITIONS FOR BIOLOGICAL TREATMENT PROCESSES

As with any biological or mechanical systems, problems can occur. The most common problems encountered in the operation of an activated sludge system include, but are not limited to the following:

- **SLUDGE BULKING**
- **RISING SLUDGE**
- **ASHING**
- **FILAMENTOUS BACTERIA**
- **ODOUR**
- **PIN-POINT FLOC**
- **STRAGGLER FLOC**
- **PLUGGING OF WITHDRAWAL PORTS**
- **SOLIDS WASHOUT**
- **FOULING OF WEIRS**
- **FOAMING**
- **PESTS**

4.1 SLUDGE BULKING

A. FILAMENTOUS BULKING

Possible causes include:

(i) Filamentous organisms extend in significant numbers from the floc into the bulk solution.
(ii) Low F/M ratio;
(iii) Low dissolved oxygen concentration in the aeration tank;
(iv) Insufficient levels of P, N or other nutrients (industrial loads entering the treatment plant are deficient in these nutrients and dilute the nutrient concentration in the aeration tank, e.g. brewery waste can promote the growth of Thiorhrix spp. and Sphaerotilus);
(v) Too high or low pH values. Fungi predominate at low pH;
(vi) High waste water temperatures; widely fluctuating organic loading rates; industrial waste waters with a high BOD; or industrial waste waters with a high sulphide content, e.g. tannery waste or septic waste water, which can promote the growth of Thiotrix spp. and Beggiatoa spp.

Practical control methods of activated sludge bulking include:

(i) Identifying the type of filamentous organism in order to understand the nature of the problem;
(ii) Applying anoxic selector zones to certain bulking/foaming conditions.

B. NON-FILAMENTOUS BULKING

Bulking can occur without filamentous organisms being present. This can occur in certain high F/M situations. If such a situation exists the operator should decrease sludge wasting.

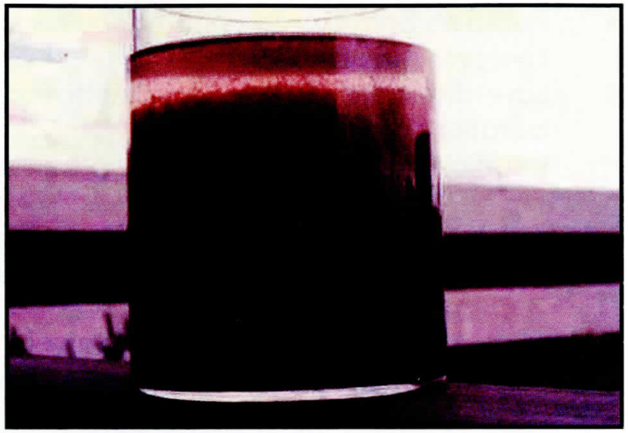

Figure 4.1 *Sludge bulking in an activated sludge process (Source: http://www.4enveng.com)*

Figure 4.2 *Sludge bulking in an activated sludge process (Source : http://www.qmes.nl)*

4.2 RISING SLUDGE

Possible causes include:

(i) Sludge is being retained in the secondary settlement tank for too long a period. Denitrification occurs in secondary settlement tanks when oxidized nitrogen is reduced to molecular nitrogen in the absence of dissolved oxygen. Bubbles of N^2 adsorb to solid particles, causing them to rise.

(ii) Plants are operated at low F/M's and nitrification takes place

(iii) High temperature

(iv) The sludge blanket in the secondary settlement tank having a low dissolved oxygen (<0.5 mg/l); and contain nitrate concentrations in excess of 5 mg/l.

Practical control methods of sludge rising include:

(i) Increasing the return activated sludge flowrate; or

(ii) Decreasing the sludge age which reduces nitrification.

Figure 4.3 *Rising Sludge in Secondary Clarifier (Source : http://www.tpomag.comhttp://web.deu.edu.tr)*

4.3 ASHING

Ashing is occasionally associated with dead cells and other sludge particles or grease floating on the surface of a settlement tank. The dead cells will not settle; the sludge may settle but not flocculate.

The possible causes are:

(i) Extremely low F/M (less than 0.05); and
(ii) MLSS containing high grease concentrations.

The problem may be resolved by:

(i) Increasing the F/M ratio and decreasing the sludge wasting rate;
(ii) Monitoring the inflow for fats, oils and grease to establish whether unusually high levels are present; and
(iii) Checking the grease removal equipment, such as baffles, is operating efficiently.

***Figure 4.4** Small ash-like particles on surface of clarifier (Source : www.ecoworld.com.vn)*

4.4 FILAMENTOUS BACTERIA

Possible causes are:

(i) Low F/M ratio;
(ii) Low dissolved oxygen concentration in the aeration tank;
(iii) Insufficient levels of P, N or other nutrients;
(iv) Low pH; and
(v) High temperature

Practical control methods include:

(i) Increasing the F/M ratio;
(ii) Decreasing the sludge age;
(iii) Removing scum at the RAS pumping area; and
(iv) Examining the sludge wasting schedule.

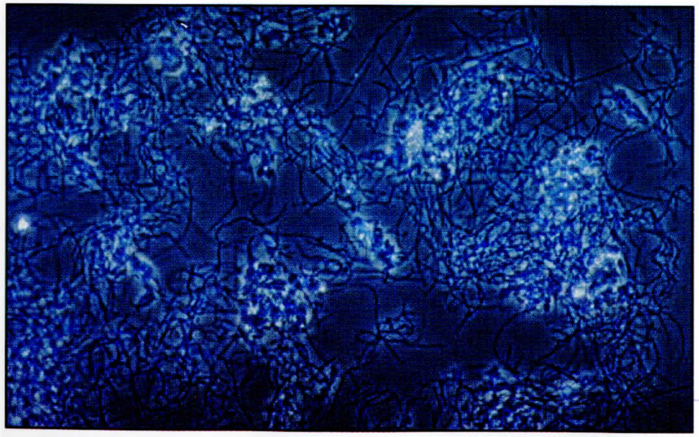

***Figure 4.5** Filamentous organism in the aeration tank (Source : http://web.deu.edu)*

.5 ODOUR

The potential sources of odours associated with primary settlement are:

(i) Inadequate scum removal;
(ii) Infrequent removal of settled solids; and
(iii) Release of odorous gases (dissolved in the primary outflow) resulting from the discharge over the weir.

The potential sources of odours associated with biofilm processes include:

(i) Insufficient oxygen;
(ii) Septic conditions as a result of hydraulic overloading or clogging;
(iii) Organic overload;
(iv) Inadequate wetting of the media; and
(v) Inadequate ventilation (stagnant airflow).

The potential sources of odours associated with activated sludge processes include:

(i) Inadequate oxygen levels in the tank (major source);
(ii) Poor mixing of the mixed liquor; and
(iii) Wetting of the walls of the aeration tank.

The potential sources of odours associated with secondary settlement tanks include:

(i) The scum removal system; and
(ii) The sludge removal system.

Practical control methods include:

(i) Primary settlement frequent cleaning of scum scrapers and pits thereby reducing the biological breakdown of grease and scum;
(ii) Frequent sludge withdrawal ensuring that solids residence times of 1 hour at average flow conditions are established;
(iii) Preventing septic conditions by reducing hydraulic retention times;
(iv) Increasing the frequency of settled solids scraping;
(v) Reducing the turbulence at the weir overflow by reducing the height of the drop between the weir overflow and the channel; and
(vi) Constructing a wind barrier if wind is a problem.

4.6 PIN-POINT FLOC

Possible causes include:

(i) Plants operating at low F/M;
(ii) Excessive turbulence in the aeration tank causing "shearing" of the floc;
(iii) Sludge settling too fast; and
(iv) SVI increasing.

Practical control methods include:

(i) Decreasing the sludge age by wasting more;
(ii) Maintaining dissolved oxygen above 2 mg/l (i.e. 2 -4 mg/L);
(iii) Adding a flocculating agent (as a temporary measure); and
(iv) Increasing the solids level by lowering the sludge wasting rate.

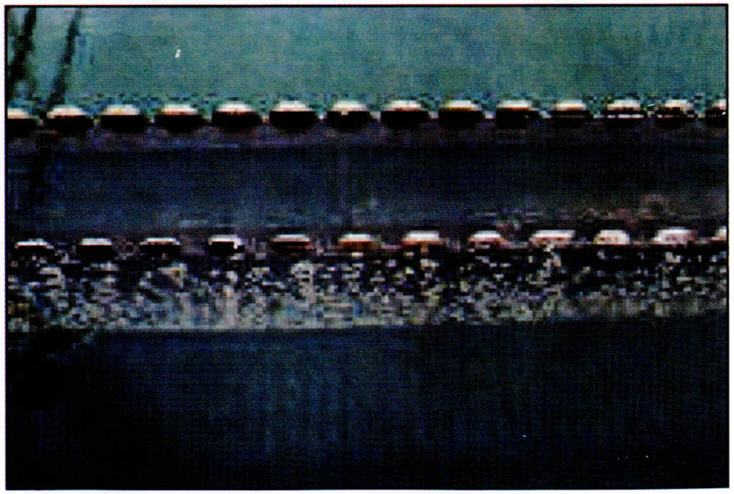

Figure 4.6 *Pin-point floc after weir*
(Source : http://water.me.vccs.edu)

4.7 STRAGGLER FLOC

Straggler floc is characterized by small, transparent and fluffy sludge particles in the settlement tank.

The causes of straggler floc are:

(i) Over aeration, particularly during process start-up; and
(ii) Low MLSS, which may result from too high a sludge wasting rate.

The problem may be resolved by:

(i) Decreasing the sludge wasting rate, thereby increasing the MLSS and the sludge age; and
(ii) Not wasting sludge during periods of high organic loading.

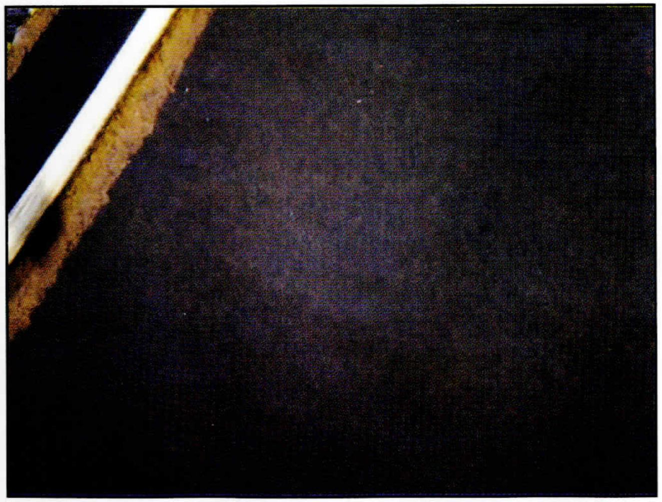

Figure 4.7 *Light fluffy sludge particles*
(Source : www.ecoworld.com.vn)

4.8 PLUGGING OF WITHDRAWAL PORTS

Possible cause includes:

(i) Too high of a solids concentration in the return sludge.

The problem may be resolved by:

(i) Withdrawing sludge faster and/or more frequently.

4.9 SOLIDS WASHOUT

The cause of solids washout is normally attributable to one or more of the following:

(i) Equipment malfunction;
(ii) Hydraulic overload; and
(iii) Solids overload

The operator should:

(i) Check all flow meters, pumps (particularly RAS), baffles and weir levels;
(ii) When two or more secondary settlement tanks are in use, it is important to ensure that all weirs are set to equal heights;
(iii) To check for hydraulic overload, inflow data should be examined for the possibility of abnormal flows and infiltration; and
(iv) To check whether there is sufficient secondary settlement tank capacity, the upward flow velocity should be checked and compared with the design value; and
(v) To prevent suspended solids from overloading secondary settlement tanks, sludge wastage rates should be increased.

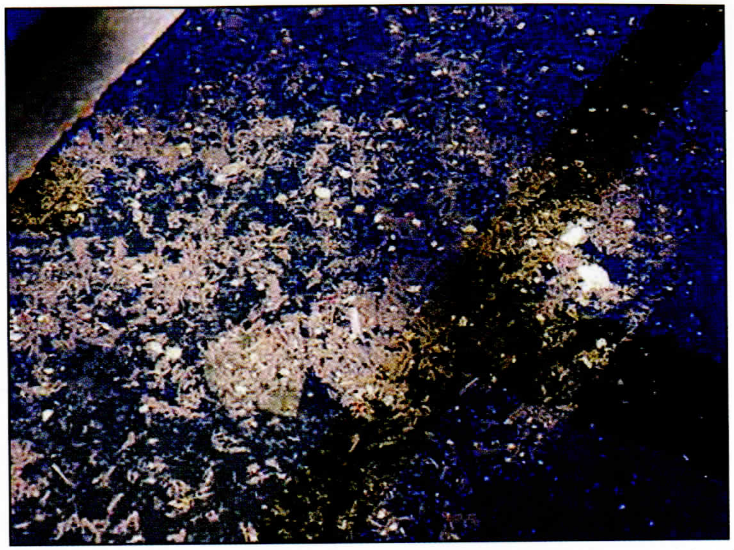

Figure 4.8 *Solids washout from the secondary settlement tank (Source : http://www.tpomag.com)*

4.10 FOULING OF WEIRS

An accumulation of solids on the weir surfaces can cause short-circuiting within the tank, creating excessive velocity currents that pull solids over the effluent weirs.

The operator should:

(i) Thoroughly scrub weir surfaces to remove solids build-up.

4.11 FOAMING

A. WHITE FOAM

Associated with:

(i) New plants;
(ii) Low sludge age;
(iii) Overloaded plants;
(iv) Low MLSS;
(v) High F/M Ratio caused by inadequate return of sludge from secondary settlement tank to aeration basin;
(vi) Excessive wasting of activated sludge;
(vii) High organic loading after a prolonged period of low loading (e.g. weekends);
(viii) Toxic material;
(ix) Low or high pH;
(x) Change in temperature;
(xi) Low dissolved oxygen;
(xii) P or N deficiency;
(xiii) Shock hydraulic loading or solids washout; and
(xiv) Poor distribution of flow and solids to secondary settlement tanks.

Corrective actions include:

(i) Check return sludge rate;
(ii) Maintain the sludge blanket at 0.3-l.0 m from the bottom of the secondary settlement tank;
(iii) Increase the MLSS in the aeration tank by not wasting sludge;
(iv) Seed the aeration plant and take steps to prevent the entry of toxic material;
(v) Monitor/inspect the discharge of significant industrial discharges; and
(vi) Balance the distribution of flow to the secondary settlement tanks.

B. EXCESSIVE BROWN FOAMS

Associated with:

(i) Plants operating at low loading rates;
(ii) Plants capable of nitrification;
(iii) Significant presence of Nocardia spp. (filamentous micro-organism);
(iv) Plants with sludge re-aeration;
(v) High sludge age caused by low F/M ratio; and
(vi) Unplanned sludge wasting event.

Corrective actions include:

(i) If nitrification is not required, increase the F/M ratio and decrease the sludge age;
(ii) Remove scum at the RAS pumping area; and
(iii) Examine the sludge wasting schedule.

C. BLACK FOAMS

Associated with:

(i) Low dissolved oxygen;
(ii) Anaerobic conditions; and
(iii) Dyes from industrial sources.

Corrective actions include:

(i) Increase aeration;
(ii) Decrease MLSS; and
(iii) Investigate industrial sources.

Figure 4.9 *Foaming in the aeration tank*
(Source : http://www.tpomag.com)

Figure 4.10 *Normal foaming in the aeration tank*
(Source : http://www.wrights-trainingsite.com)

4.12 PESTS

The fly Psychoda is the chief nuisance insect associated with some biofilm processes. These flies require an alternative wet and dry environment for growth and are normally associated with low rate systems.

Controls include:

(i) Increasing the recirculation rate which has the effect of washing the larvae off the media;
(ii) On percolating filters, maintaining the gates of the distribution arm clear at all times; and
(iii) Applying an approved insecticide to the filter structures.

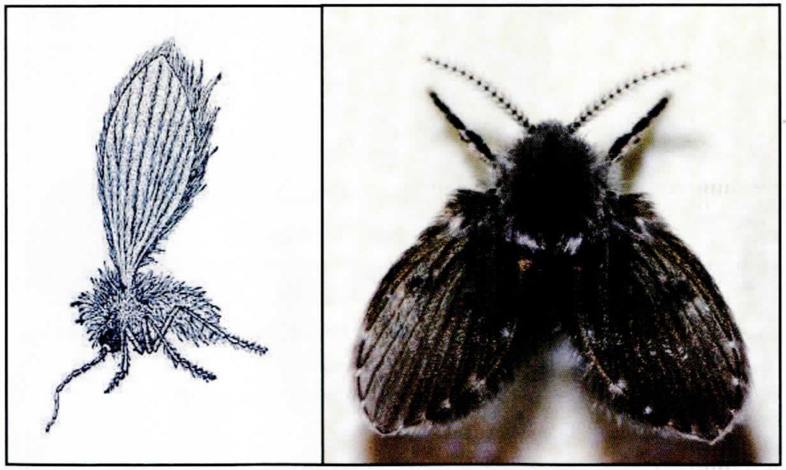

Figure 4.11 *Moth Fly, Psychoda sp.*
(Source : http://www.metafysica.nl)

4.13 TYPICAL UPSET CONDITIONS FOR PHYSICAL CHEMICAL TREATMENT PROCESSES

The following provides a list of commonly encountered problems in the operation of physical chemical treatment processes and a listing of remedies.

- **MEMBRANE FOULING**
- **FOAMING**
- **PIN-POINT FLOC (AFTER WEIR)**

4.14 MEMBRANE FOULING

Fouling in membrane filtration process is caused by:

(i) Excessive presence of suspended solids and organic contaminants.

Practical control method includes:

(i) Presence of suspended solids and organic contaminants needs to be closely monitored.

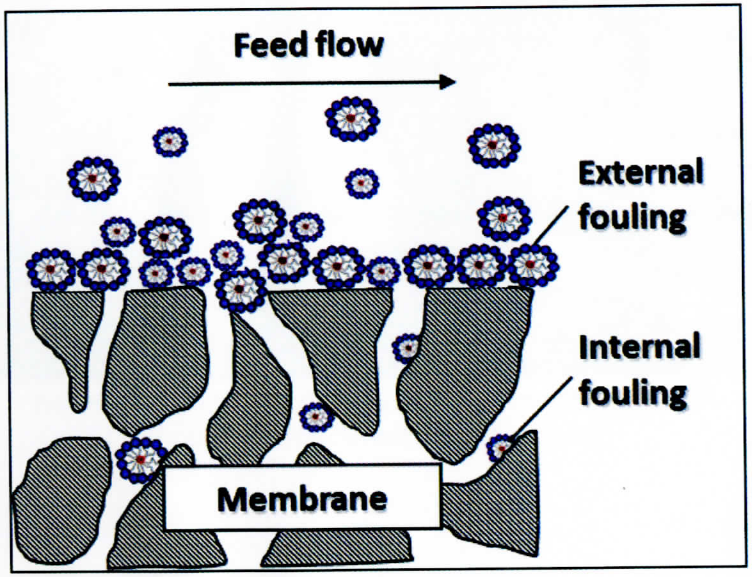

Figure 4.12 *Membrane fouling problem in membrane filtration process*
(Source : http://www.shamskm.com)

4.15 FOAMING

Foaming is a common problem in the operation of evaporators due to **dissolved or entrained gases** which can be addressed by **adding antifoam chemicals** to the feed solution.

Figure 4.13 *Foaming in the operation of the evaporators (Source : https://farm9.staticflickr.com)*

4.16 PIN-POINT FLOC (AFTER WEIR)

Possible cause includes:

(i) Ineffective coagulation and flocculation process.

Practical control method includes:

(i) Check chemical dosing via jar test.

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CONVERSION FACTORS

Mass	**1 kg**	**2.205 lb**
	1 lb	**0.4536 kg**
	1 tonne	**0.9842 tons**
	1 ton	**1.016 tonnes**
Length	**1 mm**	**0.03937 in**
	1 in	**25.4 mm**
	1 m	**3.281 ft**
	1 ft	**0.3048 m**
	1 m	**1.094 yd**
	1 yd	**0.9144 m**
Area	**1 mm^2**	**0.00153 in^2**
	1 in^2	**645.2 mm^2**
	1 m^2	**10.764 ft^2**
	1 ft^2	**0.0929 m^2**
	1 m^2	**1.196 yd^2**
	1 yd^2	**0.8361 m^2**
Volume	**1 mm^3**	**0.000061 in^3**
	1 in^3	**16 390 mm^3**
	1 m^3	**35.32 ft^3**
	1 ft^3	**0.0283 m^3**
	1 m^3	**1.308 yd^3**
	1 yd^3	**0.7646 m^3**
Density	**1 kg/m^3**	**0.06242 lb/ft^3**
	1 lb/ft^3	**16.02 kg/m^3**
	1 $tonne/m^3$	**0.7524 ton/yd^3**
	1 ton/yd^3	**1.329 $tonne/m^3$**

SUMMARY OF PCP COMPUTATIONS

Computation for	Formula
Average daily flow	Average daily flow = $\frac{\text{Totalizer reading}_2 - \text{Totalizer reading}_1}{T_2 - T_1}$
Detention time (D.T.)	Detention time (D.T.) = $\frac{\text{Tank volume (V)}}{\text{Flow (Q)}}$
Discharge rate	Discharge = $\frac{\text{Volume}}{\text{Time}}$
Chemical concentration, mg/L	1% = 10.000 mg/L
Concentration of resultant mixture (%)	Resultant mixture (%) = $\frac{V_1 \%_1 + V_2 \%_2}{V_1 + V_2}$
Volume of stock solution , mL	Volume of stock solution ,mL = $\frac{\text{Dose of solution required (\%w/v) x Final volume (mL)}}{\text{SG x stock solution strength (\%w/v)}}$

Computation for	Formula
Mass of dry chemical (g)	Mass of dry chemical ,g = $\frac{\text{Solution dose required (\%w/v) x Final volume (mL)}}{\text{100 (\%)}}$
Actual weight of chemical required	Actual weight of chemical required = $\frac{\text{Estimated weight of pure chemical}}{\text{Purity}}$
Producing a solution with desired %:	% Chemical required = $\frac{\text{(weight of chemical) (100\%)}}{\text{weight of water}}$
Chemical feeder setting	Chemical feeder setting, kg/d = $\frac{(\text{Flow, m}^3\text{/d}) \text{ (Dose, mg/L)}}{1000}$ Or in kg/h = $\frac{(\text{Flow, m}^3\text{/d}) \text{ (Dose, mg/L)/1000}}{\text{24 h/d}}$
Polymer dose mg /min	Polymer dose, mg /min = (Flow, L/min) x (Dose, mg/L)
Chemical feed rate mL/min	Chemical feed rate ,mL/min = $\frac{(\text{Flow, m}^3\text{/d}) \text{ (Dose, mg/L)}}{\text{(Chemical concentration, mg/mL)}}$

Computation for	Formula
Effluent normality, N	Effluent normality, N = $\frac{\text{(Acid volume, mL) (Acid normality, N)}}{\text{(Sample volume, mL)}}$
For continuous treatment: Acid flow, mL/s	(Acid flow, mL/s) (Acid, N) = (Effluent flow, mL/s) (Effluent, N)
For batch treatment Acid, L	(Acid, L) = $\frac{\text{(Effluent, L) (Effluent, N)}}{\text{(Acid, N)}}$
Caustic volume, C_t	$(C_t) = [(C_s)\ (\%_s)\ /V_s] \times [V_t\ /(\%_t)]$

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62574 PUTRAJAYA
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JALAN DATUK ABANG ABDUL RAHIM
93450 KUCHING
TEL: 082-482535 / 339538 / 347925

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88450 KOTA KINABALU
TEL: 088-488166 / 169 / 172

JABATAN ALAM SEKITAR W.P. LABUAN
TINGKAT 4, BLOK 4,
KOMPLEKS UJANA KEWANGAN
87007 LABUAN
TEL: 087-408772

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DEPARTMENT OF ENVIRONMENT

MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT
UNIVERSITI KEBANGSAAN MALAYSIA CAMPUS
LOCKED BAG NO. 24, 43600, UKM BANGI
SELANGOR, MALAYSIA
TEL: +603-89261500 FAX: +603-89261700
WEBSITE: http://www.doe.gov.my/eimas