OPTIMISATION OF ACTIVATED SLUDGE PROCESS

INTRODUCTION

The present document is elaborated in order to help industrials to optimise their ASP.

In a first part, general rules are exposed, concerning the required data allowing this present work to be useful.

In a second part, a Word document is presented ; it contains five parts :

- data about the present operating conditions,
- formula allowing to assess the theoretical operating conditions,
- summary allowing to compare the two previous parts,
- propositions about optimisation,
- annexes presenting different useful tools in order to interpret the plant operating :
  - concentration of pollutants that make prebiological treatment desirable,
  - optimal values for inlet waste water,
  - F/M ratio and correlation with other operating parameters,
  - optimal values for clarifier and sludge recycling,
  - mixed liquor microscopic interpretation : filamentous bacteria, microfauna and relationship with operating conditions,
  - standards and calibration solutions for some water analysis.

The calculations allowing to optimise the operating conditions are presented in an **Activated Sludge Process Optimisation : Calculations**.

FIRST PART : GENERAL RULES CONCERNING THE REQUIRED DATA

1. Flow measurement

The present tool requires data about volume flow rates :

- for inlet raw water (in the aeration tank),
- for recycled sludge,
- for extracted sludge.

2. Analysis of water

The data regarding the present operating conditions should be reliable. All the reagents should be properly labelled : chemical, date, concentration, hazard. Some analysis calibrations should be carried out regularly.

Calibration techniques are presented in annexes, concerning the most difficult analysis, or regarding analysis for which calibration is rarely performed :

- COD,
- BOD,
- oxidation-reduction potential,
- dissolved oxygen.

SECOND PART : OPERATING PARAMETERS FOR ACTIVATED SLUDGE PROCESS ASP

0. Caption

Parameter	Definition
2.3	Weight (mg) of O_2 recovered by the denitrification of 1mgN.NO_3
4.3	Weight (mg) of O_2 necessary to nitrify 1mg N.NH_3
a'	Weight (mg) of oxygen needed to oxidise 1mg BOD_5
a_m	Weight (mg) of SS issue from the growth of 1mg MLVSS
b	Weight (mg) of SS released from the lysis of 1 mg MLVSS, per day
b'	Weight (mg) of oxygen needed to oxidise 1mg MLVSS, per day
$BOD_{5\,M}$	Maximum inlet waste water BOD_5
BOD_5	Biochemical Oxygen Demand in 5 days
$[BOD_5]_{T\,oWW}$	Theoretical purpose for outlet BOD_5 concentration
C	Correction coefficient (for oxygen dissolution in mixed liquor)
c'	recovering yield of oxygen issued from denitrification
COD	Chemical Oxygen Demand
DS	Dry Solids
E	Energy consumption (for aerators)
ES	Extracted Sludge
F/M ratio	Food / Microorganism ratio
F_{ES}	Sludge Extraction volume flow rate (present data)
F_{RS}	Sludge Recirculation volume flow rate (present data)
F_{TES}	Theoretical sludge extraction volume flow rate
F_{TRS}	Theoretical sludge recirculation volume flow rate
H	Height (for settling tank)
HO	Hourly oxygen transfer capacity
iWW	inlet Waste Water
Le	BOD_5 mass flow rate to be removed (Lye effluent)
M	Maximum value in inlet waste water (for q_v, BOD_5, N.NH_3, TKN, SS...)
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
N	N.NH_3 to be nitrified (mass flow rate)
$O_{2\,T}$	Theoretical oxygen need (mass flow rate)
OC	Oxygen capacity
ORP	Oxidation Reduction Potential
Parameter	**Definition**
oWW	outlet Waste Water
$q_{v\,max}$	maximum inlet waste water volume flow rate
S	Surface (for settling tank)
SA	Sludge Age

Sf	SS flow in outlet settled water (mass flow rate)
SOTC	Specific oxygen transfer capacity
SS	Suspended Solids
Sv	Sludge Volatile : weight of MLVSS in aeration tank
SVI	Sludge Volume Index
t	Running time (for aerators) : hours /d
T o WW	Theoretical outlet Waste Water (purpose of the treatment)
TKN	Total Kjeldahl Nitrogen
UV	Upward velocity
V_{30}	Sludge volume after 30 min mixed liquor settling in a 1L-cylinder
V_{AT}	Aeration Tank Volume

1. Present data about the plant

1.1. WW and eventually standard

Average values	iWW	oWW	Purpose of the treatment or discharge standard
q_v (m^3/ d)			
ORP (V)			
T (°C)			
pH			
[SS] (kg/m^3)			
[BOD_5] (kgO_2 / m^3)			
[COD] (kgO_2 / m^3)			
[TKN] (kg/m^3)			
[N.NH_3] (kg / m^3)			
[N.NO_3^-] (kg/m^3)			
[P] (kg/m^3)			
[oil] (mg / L)			
[Pb] (mg / L)			
[Cu + Ni + CN] (mg/L)			
[Cr VI + Zn] (mg / L)			
[CrIII](mg / L)			
alcalinity (mg$CaCO_3$/L)			
[sulfides] (mg / L)			
[phenols] (mg / L)			
[DS] (g / L)			

Flow variation :

	maximum	average
q_v (m^3 / d)		
[BOD_5](kgO_2 / m^3)		
[N.NH_3](kg / m^3)		

1.2. Aerated tank

1.2.1. Tank sizing

V_{AT} (m^3) :

Shape : Tick off the box or precise

Circular	
Rectangular	

1.2.2. Aerator

Number n =

Type (Surface aerators, aeration by compressed air…) :

HO (kgO_2 / h) =

OC ($kgO_2 . h^{-1} . m^{-3}$) =

SOTC (kgO_2 / kWh) =

E (kWh / d) =

t (d) =

C (0 to 1) =

Eventual aeration regulation : tick off the box and

Process regulation according	
time : precise the duration	
O_2 : precise the thresholds	
ORP : precise the thresholds	

1.2.3. Mixed liquor

1.2.3.1. SS concentrations

[MLSS] (kg / m^3) =

[MLVSS] (kg / m^3) =

1.2.3.2. Mixed liquor aspect

Colour :

Odour :

Eventual foam description :

1.2.3.3. Microscopic observation

1.2.3.3.1. Floc quality (Compact, Fairly compact) :

1.2.3.3.2. Microfauna (Tick off the box)

		Proportionally numerous	Proportionally few	Proportionally rare
Free bacteria				
Protozoan	Ciliated			
	Flagellated			
	Amoeba			
Metazoan				

1.2.3.3.3. Filamentous bacteria description

1.2.3.3.3.1. Wet-mount technique

Length (Short, Long):

Ramification (None, Real, False) :

Rigid / Supple :

Sheathed :

Partitioned cells :

Rectangular / ovoid cells :

Sulphur granules :

1.2.3.3.3.2. Stream colour

Gram (+ / -) :

Neisser (+ / -) :

Sulphite (+ / -)

1.3 Settling tank

H (m) =

S (m^2) =

V_{30} (mL / L) =

Eventual dilution (dilution factor) :

Eventual foam description :

1.4 Extracted sludge

$[SS]_{ES}$ (kg/m^3) =

F_{ES} (m^3 / d) =

1.5 Recirculated sludge

F_{RS} (m^3 / d) =

2. Theoretical sizing

2.1. WW

	value
Biodegradability ratio COD / BOD_5	
BOD_5/N/P	

Maximum mass discharge rate / average mass discharge rate =

2.2. Aerated tank

2.2.1. Tank sizing

F/M ratio (kg BOD_5 . kg $MLVSS^{-1}$. d^{-1}) = $[BOD_5]_M$ x q_{vM} / ([MLVSS] x V_{AT})

Calculation : F/M ratio (kg BOD_5 . kg $MLVSS^{-1}$. d^{-1}) =

2.2.2. Aerator

2.2.2.1. Theoretical daily needs of oxygen O_{2T}

$O_{2\,T}$ (kg O_2 /d) = a' Le + b' Sv + 4.3 N (*if nitrification*) – c' 2.3 N (*if denitrification*)

a' and b' constants values

Parameter	unit	High load	Medium load	Low load	Extended aeration
F/M	(kg BOD_5.kg $MLVSS^{-1}$. d^{-1})	> 0.5	0.2 to 0.5	0.1 to 0.2	< 0.1
a'	kgO_2 / $kgBOD_{5\ removed}$	0.5	0.6	0.7	0.7
b'	kgO_2 . $kgMLVSS^{-1}$. d^{-1}	0.07	0.075	0.08	0.08

Le (kg BOD_5 / d) = ($[BOD_5]_M$ -$[BOD_5]_{T\ oWW}$) x $q_{v\,M}$

Sv (kg MLVSS) = [MLVSS] x V_{AT}

N = [0.8 ($[TKN]_M$ – $[N.NH_3]_M$) + $[N.NH_3]_M$ – 0.05($[BOD_5]_M$-$[BOD_5]_{T\ oWW}$)]x$q_{v\,M}$

c' = 0.75

Calculation : $O_{2\ T}$ (kg O_2/ d) =

2.2.2.2. Present oxygen supply

$O_{2\,P}$ (kg O_2/ d) = n x SOTC x E x t x C

or

$O_{2\,P}$ (kg O_2/ d) = n x HO x t x C

Calculation : $O_{2\,P}$ (kg O_2/ d) =

2.3 Settling tank

Upward velocity UV (m/h) = $q_{v\,M}$ / S

Calculation : UV (m/h) =

SVI (mL / g) = V_{30} / [MLSS]

Calculation : SVI (mL /g) =

2.4. Theoretical sludge extraction flow FTES

F_{TES} (m^3 / d) = [a_m $Le_{removed}$ – b Sv + S + Sf] / $[SS]_{ES}$

Parameter	unit	High load	Medium load	Low load	Extended aeration
F/M	(kg BOD_5.kg $MLVSS^{-1}$. d^{-1})	> 0.5	0.2 à 0.5	0.1 à 0.2	< 0.1
a_m	kg SS / kg$BOD_{5\,removed}$	0.45	0.6	0.7	0.7
b	kg SS . kg$MLVSS^{-1}$. d^{-1}	0.03	0.05	0.06	0.07

Le (kg BOD_5 / d) = ($[BOD_5]_M$ -$[BOD_5]_{T\,oWW}$) x $q_{v\,M}$

S (kg SS /d) = 0.5 x $[SS]_M$ x $q_{v\,M}$

Sf (kg SS /d) = $[SS]_{T\,oWW}$ x $q_{v\,M}$

Calculation : F_{TES} (m^3/d) =

2.5. Sludge age SA

SA (d) = ([MLSS] x V_{AT})/ (F_{ES} x $[SS]_{ES}$)

Calculation : SA (d) =

2.6. Sludge recirculation

F_{TRS} (m^3 / d) = [[MLSS] / ($[SS]_{ES}$ –[MLSS])] x $q_{v\,M}$

Calculation :F_{TRS} (m^3/d) =

3. Summary

3.1. iWW quality

1.1.Concentration of pollutants that make prebiological treatment desirable (from Activated Sludge Treatment Industrial Wastewater, W.W. Eckenfelder, J.L. Musterman, 1995)

Pollutant or System Condition	**Limiting concentration**
[SS]	125 mg / L
[oil]	50 mg / L
[Pb]	0.1 mg / L
[Cu + Ni + CN]	1 mg / L
[Cr VI + Zn]	3 mg / L
[CrIII]	10 mg / L
alcalinity	0.5g $CaCO_3$ / $gBOD_{5\ removed}$
[sulphides]	100mg / L
[phenols]	300mg / L
[ammonia]	500mgN / L
[DS]	16 g / L

1.2. Optimal values for inlet waste water

Maximum mass discharge rate / average mass discharge rate should be < 1.2

Parameters	**optimal value**
Biodegradability ratio COD / BOD_5	< 3
BOD_5/N/P	100 / 5 / 1
pH	6 to 9
T (°C)	13 to 38

3.2. F/M ratio

Parameter	**unit**	**High load**	**Medium load**	**Low load**	**Extended aeration**
F/M	(kg BOD_5 . kg $MLVSS^{-1}$. d^{-1})	> 0.5	0.2 à 0.5	0.1 à 0.2	< 0.1
SA	d	1	2 to 8	>10	>15
nitrification		none	beginning	medium	efficient
bioflocculation		none	medium	efficient	
BOD removal efficiency	%	70	85 to 93	90 to 97	

3.3. SVI and settling

	optimal value
SVI (ml / g)	< 150
Upward velocity (m/h)	< 1
recycling volume flow rate/ $q_{V\ M}$	1 if proper settle ability 1 to 2 if difficult settle ability

3.4. Mixed liquor microscopic observations

4.1) Standard solution for COD measurement

Potassium hydrogenophtalate $KC_8H_5O_4$ 0.04253 g/L (0.20824 mmol / L) presents a COD = 500mgO_2/L.

4.2) Standard solution for BOD measurement

(150 mg of glucose + 150 mg of glutamic acid) / L presents a
BOD = 220 +/- 18 mg O_2 / L

4.3) Redox potential measuring - eH meter

Principle : eH measures the quantity of oxidations and reductions in a solution ; it is a voltage measure.

As pH meter sensors, eh sensor consists of 2 electrodes, combined or separated :

- reference electrode ; contrary to pH meter reference, there are a lot of sorts of references : calomel, silver (Ag , AgCl), Hg_2SO_4…

The measured potential must be recalculated in comparison to the standard hydrogen electrode (E° H^+ / H_2 = 0 V).

Read the notice :

- to know if the indicated value is already expressed in comparison to standard hydrogen electrode
- if it is not, to know the difference with the standard hydrogen electrode

For example :

* add 248mV if the reference is calomel at 20°C, + 244.4 mV at 25 °C
* add 199mV if the reference is Ag , AgCl, at 25°C….

- measuring electrode : platinum wire

Calibration :

Two kinds of buffers :

* quinhydrone 1 g . L^{-1} in pH 4 buffer : at 25°C :

E H^+ / H_2 = 462 mV

E calomel = 218 mV

* Fe^{2+} / Fe^{3+} :

- ferrous ammonium sulphate [$Fe(NH_4)_2(SO_4)_2$, $6H_20$] : 39,2g (M = 392 g.mol^{-1})
- ferric ammonium sulphate [$FeNH_4(SO_4)_2$, $12H_20$] : 48,2 g (M = 482 g.mol^{-1})

in 700 mL distillated water

add 28.1 mL concentrated sulphuric acid ([H_2SO_4]final = 0.5M)

Fill up to 1L with distillated water

In this buffer, Fe^{2+} = Fer^{3+} = 0.1mol / L

Then E = E° = 0.68V at 25°C

Read potential with reference:

- calomel : 0.68 – 0.244 = 0.436 V
- AgCl 3.5M : 0.68 – 0.199 = 0.481 V
- AgCl 1M : 0.68 – 0.236 = 0.444V

Maintenance : regular sensor mechanic cleaning

4.4) Oxygen concentration determination in water

Principle

Water oxygen concentration units are : mg O_2 / L or saturation percentage (%) .

The saturation percentage is measured in comparison to the oxygen concentration in a demineralized water, at the same temperature :

If T = 0°C, 100 % = 14,6 mg O_2 / L

T = 20 °C, saturation for 9.2 mg O_2 / L.

The measurement must be done in **stirred** water because oxygen is consumed at the membrane level (30 to 50 cm / s). Some oxymeters have an incorporated stirrer.
A temperature increase induces a oxygen concentration decrease. The oxymeter measures water temperature and translates the concentration value in a saturation percentage value.
Calibration :
- 0 % in a **saturated** sodium sulphite (Na_2SO_3) solution
- 100 % in the air.

Maintenance :
The membrane is very vulnerable.
The membrane and the electrolyte must be changed regularly ; the electrodes must be cleaned.