

Spreadsheet for the optimized design of a conventional activated sludge system for secondary treatment

System configuration consists of an aeration tank, final settler, sludge thickener and anaerobic digester
It is assumed that nitrification does not develop

Section 1: Input data

1. General data for the activated sludge system

Y =	0,45	b =	0,24	k =	0,46	Sfd =	2
fcv =	1,5	fv =	0,7	vo =	144	Sfth =	1,5
f =	0,2	eta =	1,2	DSVI =	120	Hd =	4
fn =	0,1					Hth =	3
fp =	0,025						

2. Influent composition

Qi =	12000	Sti =	650	Nti =	50	T min =	20
P.E. =	77515	fns =	0,1	Pti =	15	T max =	24
		fnp =	0,08			T dig =	20

3. Financial data

Cr =	175	i =	0,06	Cel =	0,15	p =	3,0	% of the investments costs per year
Cd =	300	n =	20	Csd =	200	o =	1,0	% of the investments costs per year
Cth =	400			Ch =	0,35	m =	2,0	% of the investments costs per year
Cdi =	350			fac =	1,6	n =	0,3	% of the investments costs per year
Cae =	3500			fi =	1,35			

Section 2: System calculations

Rs = 3 COD removal is substantially complete at lower values of Rs: higher value is required to obtain a sludge that settles well

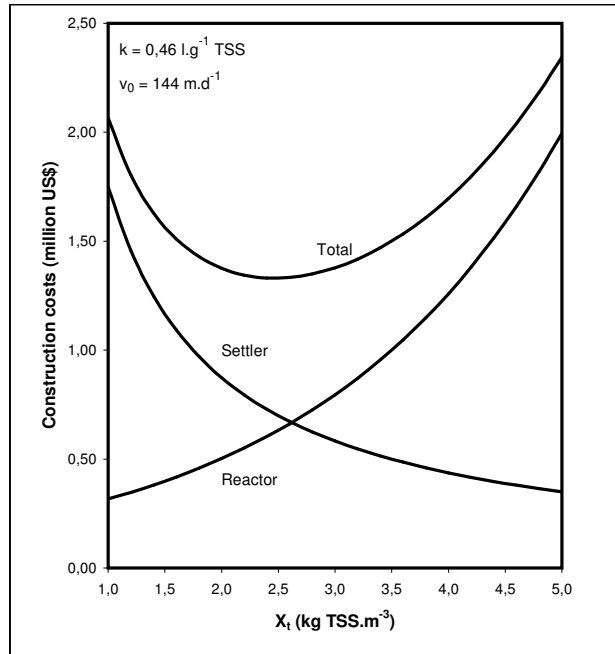
A - Optimisation of the System Consisting of the Aeration Tank and the Final Settler

(a1) Calculate the sludge mass that will develop

mXa =	0,64	MXa =	5020	Xa	1,21
mXe =	0,09	MXe =	723		
mXi =	0,16	MXi =	1248		
mXv =	0,90	MXv =	6991	Xv	1,68
mXt =	1,28	MXt =	9987	fat	0,50
Cr =	0,78				

(a2) Determine the optimal sludge concentration in the aeration tank

Xt	Vr	Vd	total construction costs		construction costs in million dollars	
			costs	aeration tank	final settler	total
1,0	9,987	1,056	2.064.568	1,75	0,32	2,06
1,2	8,323	1,158	1.803.806	1,46	0,35	1,80
1,4	7,134	1,269	1.629.212	1,25	0,38	1,63
1,6	6,242	1,392	1.509.859	1,09	0,42	1,51
1,8	5,548	1,526	1.428.721	0,97	0,46	1,43
2,0	4,994	1,673	1.375.735	0,87	0,50	1,38
2,2	4,540	1,834	1.344.653	0,79	0,55	1,34
2,4	4,161	2,011	1.331.472	0,73	0,60	1,33
2,6	3,841	2,205	1.333.585	0,67	0,66	1,33
2,8	3,567	2,417	1.349.303	0,62	0,73	1,35
3,0	3,329	2,650	1.377.565	0,58	0,79	1,38
3,2	3,121	2,905	1.417.761	0,55	0,87	1,42
3,4	2,937	3,185	1.469.624	0,51	0,96	1,47
3,6	2,774	3,492	1.533.150	0,49	1,05	1,53
3,8	2,628	3,829	1.608.556	0,46	1,15	1,61
4,0	2,497	4,198	1.696.246	0,44	1,26	1,70
4,2	2,378	4,602	1.796.792	0,42	1,38	1,80
4,4	2,270	5,046	1.910.924	0,40	1,51	1,91
4,6	2,171	5,532	2.039.522	0,38	1,66	2,04
4,8	2,081	6,065	2.183.616	0,36	1,82	2,18
5,0	1,997	6,649	2.344.387	0,35	1,99	2,34
5,2	1,921	7,290	2.523.175	0,34	2,19	2,52
5,4	1,849	7,993	2.721.483	0,32	2,40	2,72
5,6	1,783	8,763	2.940.990	0,31	2,63	2,94
5,8	1,722	9,607	3.183.560	0,30	2,88	3,18
6,0	1,665	10,533	3.451.261	0,29	3,16	3,45
6,2	1,611	11,548	3.746.374	0,28	3,46	3,75
6,4	1,560	12,661	4.071.419	0,27	3,80	4,07
6,6	1,513	13,881	4.429.169	0,26	4,16	4,43
6,8	1,469	15,219	4.822.678	0,26	4,57	4,82
7,0	1,427	16,685	5.255.303	0,25	5,01	5,26



Optimal (minimal costs) solution =

Xt = **2,40**
 Vr = 4,161
 Vd = 2,011

!! Enter in the cell to the left the value of Xt for which the construction costs are minimum !!

Vx = 288 Rhdmax = 3,0 for s = sc
 kXt = 1,104 Rdh = 2,0 for s = 1
 sc = 0,35 Xr = 4,8 for s = 1

B - Optimization of the System Consisting of Sludge Thickener and Anaerobic Digester

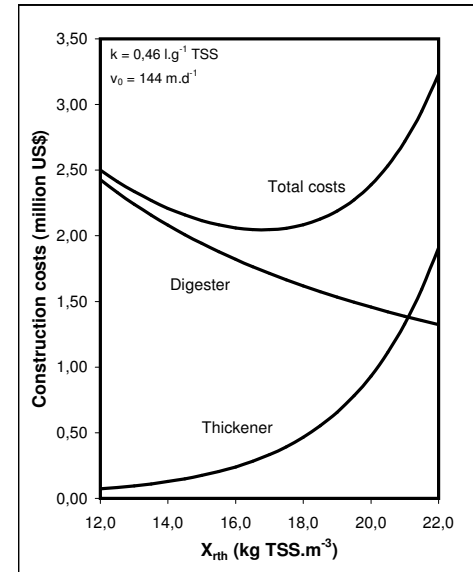
(b1) Determine the optimum thickened sludge concentration

q = 1387
MEt = 3329
MEv = 2330

Xthr	Xthl	Fl	qth	Vth	Vdi	total construction costs	construction costs in million dollars thickener	digester	total
12,0	9,1	82,4	277,4	182	6.936	2.500.116	0,07	2,43	2,50
12,5	9,7	72,0	266,3	208	6.658	2.413.615	0,08	2,33	2,41
13	10,2	62,5	256,1	240	6.402	2.336.560	0,10	2,24	2,34
13,5	10,8	54,1	246,6	277	6.165	2.268.491	0,11	2,16	2,27
14	11,3	46,6	237,8	321	5.945	2.209.144	0,13	2,08	2,21
14,5	11,8	40,1	229,6	374	5.740	2.158.444	0,15	2,01	2,16
15	12,4	34,3	221,9	436	5.548	2.116.510	0,17	1,94	2,12
15,5	12,9	29,3	214,8	511	5.369	2.083.663	0,20	1,88	2,08
16	13,4	25,0	208,1	600	5.202	2.060.444	0,24	1,82	2,06
16,5	13,9	21,2	201,8	706	5.044	2.047.637	0,28	1,77	2,05
17	14,4	18,0	195,8	832	4.896	2.046.306	0,33	1,71	2,05
17,5	15,0	15,2	190,2	983	4.756	2.057.838	0,39	1,66	2,06
18	15,5	12,9	184,9	1.164	4.624	2.083.999	0,47	1,62	2,08
18,5	16,0	10,8	179,9	1.381	4.499	2.127.005	0,55	1,57	2,13
19	16,5	9,1	175,2	1.641	4.380	2.189.608	0,66	1,53	2,19
19,5	17,0	7,7	170,7	1.953	4.268	2.275.204	0,78	1,49	2,28
20	17,5	6,4	166,5	2.329	4.161	2.387.965	0,93	1,46	2,39
20,5	18,0	5,4	162,4	2.780	4.060	2.533.002	1,11	1,42	2,53
21	18,5	4,5	158,5	3.324	3.963	2.716.563	1,33	1,39	2,72
21,5	19,0	3,8	154,8	3.979	3.871	2.946.274	1,59	1,35	2,95
22	19,6	3,1	151,3	4.768	3.783	3.231.441	1,91	1,32	3,23

Optimal (minimal costs) solution = **2.046.306**

Xthr = 17 !! Enter in the cell to the left the value of Xthr for which the construction costs are minimum !!
Vth = 832 Rhth = 14,4 qth = 196
Vdi = 4896 Rdi = 25,0 q - qth = 1191



C - Finalization of System Design

(c1) Nutrient demand

MNI =	233,0
MNp =	58,3
NI =	19,4
PI =	4,85
Nte =	30,6
Pte =	10,1

(c2) Oxygen demand

MSti =	7800
MOC =	3524
OUR =	35,3
Pb,avg =	122
Pb,max =	184
Pdiss =	29,4

(c3) Digester performance

fav =	0,72
MEv =	2330
Rdp =	0,494
Rdn =	0,138
MSd =	1376
MSxve =	2120
MEve =	1413
MEte =	2412
Xte =	12,3
fve =	0,59
conversion effic.	0,35
Mch4 =	344
Pch4 =	70

(c4) Mass balances

COD	(-)	kg CZV/d	Nitrogen	(-)	mg N/l	Phosphorus	(-)	mg P/l
mSte =	0,10	780	Nti =	1,00	50,0	Pti =		15
mSo =	0,45	3524	NI =	0,39	19,4	PI =	0,32	4,9
mSd =	0,18	1376	Nle =	0,24	11,8	Ple =	0,20	2,9
mSXve =	0,27	2120	Nld =	0,15	7,6	Pld =	0,13	1,9
Total =	1,00	7800	Nte,max =	0,76	38,2	Pte,max =	0,80	12,1
			Nte,min =	0,61	30,6	Pte,min =	0,68	10,1
			Total =	1,00	50,0	Total =	1,00	15,0

D - Financial Analysis

i = 0,06 a_{i,n} = 11,5
n = 20 anual = 0,087

Construction costs	Volume	Costs	Fraction of total costs	
Aeration Tank	4.161	730.000	8%	
Final Settler	2.011	600.000	7%	
Thickener	832	330.000	4%	
Digester	4.896	1.710.000	20%	
Aeration Equipment	184	640.000	7%	
Total constr. Main Units	11.900	4.010.000	46%	
Add. Constr Units		1.400.000	16%	
Total construction costs		5.410.000	62%	
Total investment costs	3.250.000	8.660.000	38%	

Annualized treatment costs	Per yer	US\$ ct per m3	US\$ ct per P.E.	Fraction
Financing cost	760.000	17,4	9,8	46%
Aeration costs	160.000	3,7	2,1	10%
Costs of sludge disposal	180.000	4,1	2,3	11%
Personnel costs	260.000	5,9	3,4	16%
Operational costs	90.000	2,1	1,2	5%
Maintenance costs	170.000	3,9	2,2	10%
Insurance costs	30.000	0,7	0,4	2%
Cost of digester heating	0	0,0	0,0	0%
Total operational costs	890.000	20,3	11,5	54%
Total costs	1.650.000	37,7	21,3	100%

Symbol list

Symbol	Description	Unit of measure
$a_{i,n}$	annualization factor	
b	decay rate	1/d
C_{ae}	construction cost of aeration system	US\$/kW
C_d	construction cost of the final settler	US\$/m ³
C_{di}	construction cost of the anaerobic digester	US\$/m ³
C_{el}	cost of electricity	US\$/kWh
C_h	cost of heating (gas)	US\$/m ³ natural gas
conversion effic	efficiency of gas motor	%
C_r	construction cost of the aeration tank	US\$/m ³
C_r	specific active sludge production per unit mass daily applied biodegradable COD	mg VSS/(mg COD/d)
C_{sd}	cost of sludge disposal	US\$/ton sludge
C_{th}	construction cost of the thickener	US\$/m ³
$DSVI$	diluted sludge volume index	ml/g TSS
η	oxygen transfer efficiency	kg O ₂ /kWh
f	endogenous residue	mg VSS/mg VSS
f_{ac}	fraction of construction costs for additional units	(-)
f_{at}	active sludge fraction	mg VSS/mg TSS
f_{av}	active fraction of volatile sludge	mg VSS/mg VSS
f_{cv}	proportionality constant between bacterial mass and mass of COD	mg COD/mg VSS
f_i	additional investment costs (non construction)	(-)
FI	limiting solids flux	kg TSS/(m ² *d)
f_n	nitrogen fraction in biomass	mg N/mg VSS
f_{np}	non biodegradable, particulate influent COD fraction	mg COD/mg COD
f_{ns}	non biodegradable, soluble influent COD fraction	mg COD/mg COD
f_p	phosphorus fraction in biomass	mg P/mg VSS
f_v	ratio between volatile and total sludge concentration	mg VSS/mg TSS
f_{ve}	volatile sludge fraction in stabilized sludge	mg VSS/mg TSS
H_d	height of final settler	m
H_{th}	height of sludge thickener	m
i	interest rate	%

Symbol	Description	Unit of measure
I =	investment costs	US\$
k =	vesilind constant	l/g TSS
m =	maintenance costs	% of I per year
Mch4 =	daily production of methane	kg CH4/d
MEt =	daily excess sludge production	kg TSS/m ³
MEte =	daily production of stabilized sludge	kg TSS/d
MEv =	daily volatile excess sludge production	kg VSS/m ³
MEve =	daily production of stabilized volatile sludge	kg VSS/d
MNI =	daily nitrogen demand for excess sludge production	kg N/d
MNp =	daily phosphorus demand for excess sludge production	kg P/d
MOc =	daily oxygen demand	kg O ₂ /d
mSd =	fraction of influent COD that is digested	(-)
MSd =	daily amount of digested COD	kg COD/d
mSo =	fraction of influent COD that is oxidized	(-)
mSte =	fraction of influent COD leaving the system with the effluent	(-)
MSti =	daily applied COD load	kg COD/d
MSxve =	daily amount of COD in the stabilized excess sludge	kg COD/d
mSXve =	fraction of influent COD leaving the system with stabilized excess sludge	(-)
mXa =	specific active sludge production per unit mass daily applied COD	mg VSS/(mg COD/d)
MXa =	total active sludge mass in system	kg VSS
mXe =	specific endogenous sludge production per unit mass daily applied COD	mg VSS/(mg COD/d)
MXe =	total endogenous sludge mass in system	kg VSS
mXi =	specific inert sludge production per unit mass daily applied COD	mg VSS/(mg COD/d)
MXi =	total inert sludge mass in system	kg VSS
mXt =	specific total sludge production per unit mass daily applied COD	mg TSS/(mg COD/d)
MXt =	total sludge mass in system	kg TSS
mXv =	specific volatile sludge production per unit mass daily applied COD	mg VSS/(mg COD/d)
MXv =	total volatile sludge mass in system	kg VSS
n =	insurance costs	% of I per year
n =	economical lifetime	years
NI =	influent Kjeldahl nitrogen concentration removed with the excess sludge	mg N/l
Nld =	influent Kjeldahl nitrogen concentration in digested sludge (i.e. released to liquid phase)	mg N/l
Nle =	influent Kjeldahl nitrogen concentration removed with the stabilized excess sludge	mg N/l

Symbol	Description	Unit of measure
Nte =	effluent total nitrogen concentration	mg N/l
Nte,max =	maximum nitrogen effluent concentration (all released nitrogen recycled to aeration tank)	mg N/l
Nte,min =	mimimum nitrogen effluent concentration (no recyle of released nitrogen to aeration tank)	mg N/l
Nti =	influent Kjeldahl nitrogen concentration	mg N/l
o =	operational costs	% of I per year
OUR =	oxygen uptake rate	mg O ₂ /(l.h)
p =	personnel costs	% of I per year
P.E. =	people equivalents	---
Pb,avg =	average blower capacity	kW
Pb,max =	maximum blower capacity	kW
Pch4 =	power recovered from sludge digestion	kW
Pdiss =	dissipated power	W/m ³
PI =	influent phosphorus concentration removed with the excess sludge	mg P/l
PI =	influent phosphorus concentration removed with the excess sludge	mg P/l
PI _d =	influent phosphorus concentration in digested sludge (i.e. released to liquid phase)	mg P/l
PI _e =	influent phosphorus concentration removed with the stabilized excess sludge	mg P/l
Pte =	effluent total phosphorus concentration	mg P/l
Pte,max =	maximum phosphorus effluent concentration (all released phosphorus recycled to aeration tank)	mg P/l
Pte,min =	mimimum phosphorus effluent concentration (no recyle of released phosphorus to aeration tank)	mg P/l
Pti =	influent phosphorus concentration	mg P/l
q =	excess sludge flow	m ³ /d
qth =	thickened excess sludge flow	m ³ /d
Rdi =	hydraulic retention time in sludge digester	days
Rdn =	degree of solids conversion inert and endogenous sludge	(-)
Rdp =	degree of solids conversion active sludge	(-)
Rs =	sludge age	days
Rth =	hydraulic retention time in sludge digester	hours

Symbol	Description	Unit of measure
sc =	critical sludge recirculation factor	(-)
Sfd =	safety factor in design final settler	(-)
Sfth =	safety factor in design sludge thickener	(-)
Sti =	influent COD concentration	mg COD/l
T dig =	temperature in the anaerobic digester	deg C
T max =	maximum reactor temperature	deg C
T min =	minimum reactor temperature	deg C
Vd =	volume of final settler	m ³
Vdi =	digester volume	m ³
vo =	vesiling constant	m/d
Vt =	volume of aeration tank	m ³
Vth =	thickener volume	m ³
Xa =	active sludge concentration (in aeration tank)	kg VSS/m ³
Xr =	return sludge concentration	kg TSS/m ³
Xt =	total sludge concentration (in aeration tank)	kg TSS/m ³
Xte =	stabilized total sludge concentration	kg TSS/m ³
Xthl =	limiting thickening sludge concentration	kg TSS/m ³
Xthr =	thickened sludge concentration	kg TSS/m ³
Xv =	volatile sludge concentration (in aeration tank)	kg VSS/m ³
Y =	yield	mg VSS/mg COD