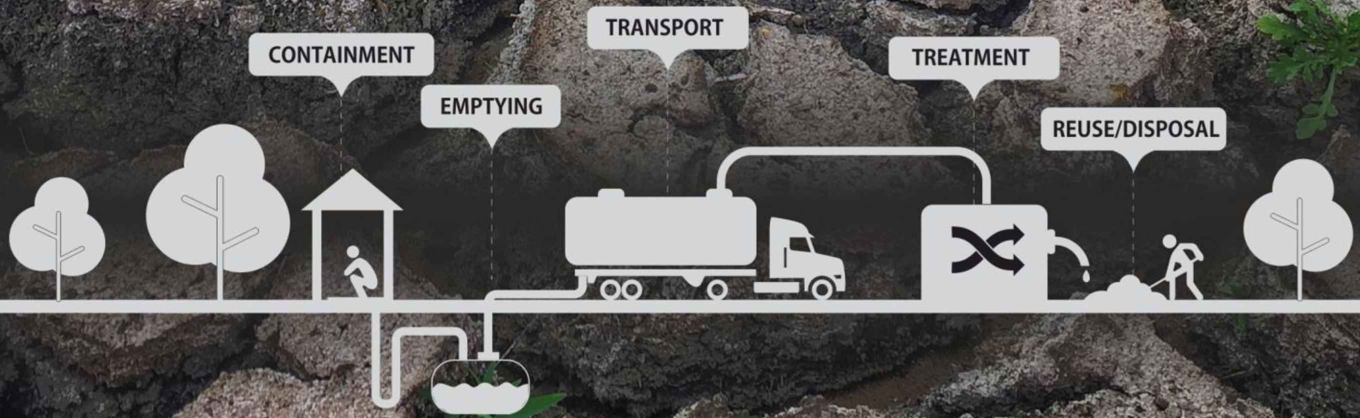
Decentralized Liquid Waste Management

Feb 18th - 21st, 2019
Department of Civil Engineering
College of Engineering Pune

Design Workbook



National Institute of Urban Affairs

Ecosan Services Foundation

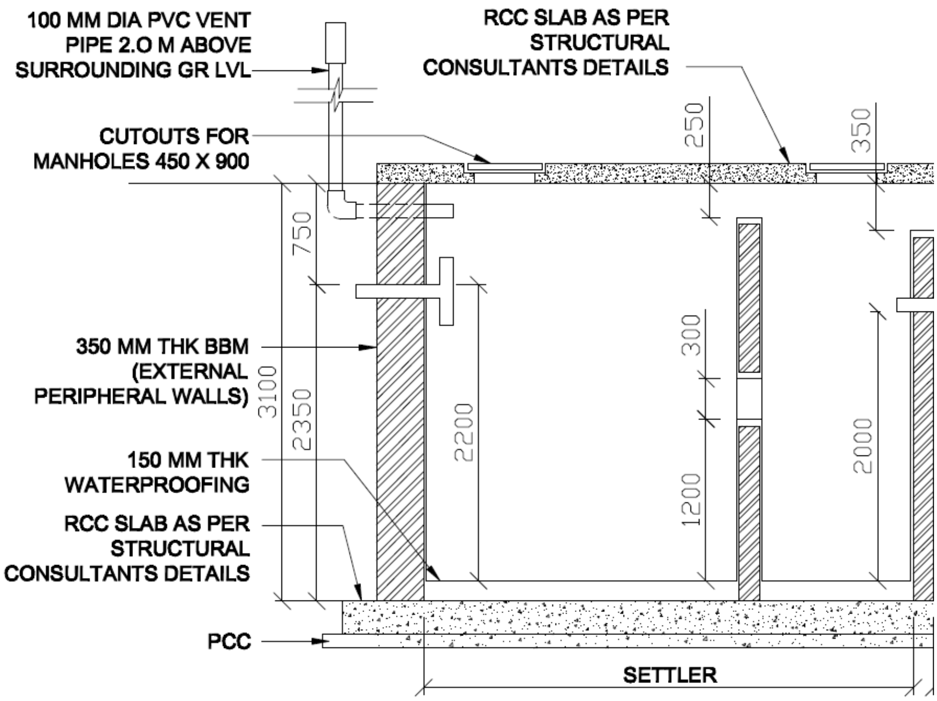
Group Work:

Design of Decentralized Treatment System – Part I

Methodology

Designing an Anaerobic Settler (AS)

Settler tanks are underground or closed tanks with two or three compartments, which are designed to retain wastewater for a required period of time and allow heavy solids to settle at the bottom.



The Hydraulic Retention Time (HRT) is 1.5-2 hours. The settled solids are partially decomposed due to anaerobic condition and form sludge and collect at the bottom. Grease and light particles floats and form a thin layer at the surface of the wastewater referred to as scum.

The first compartment occupies more than half of the volume as it retains most of the scum and sludge, whereas the following compartments ensure smooth and undisturbed flow in to the next treatment module. Partition of baffle wall is provided to avoid scum and solids entering in to the next treatment module. Required number of manhole openings is provided for easy access into the treatment system. Optimal sedimentation takes place when the flow is smooth and undisturbed.

Biological treatment is optimized by quick and intense contact between the new inflow and old sludge.

Rules of thumb during design

Area required for construction is about	0.5 to 1 m^2/m^3, usually 0.6
Efficient septic tank should remove	50-70% of suspended solids, 25-40% of BOD
Sludge volume l/g BOD removal	0.005 l sludge/g BOD
Accu. Sludge Volume	0.1 l/cap x d
Collection of sludge	24-36 months, 18-24 months. Bottom should have a gentle slope toward sludge hopper
When desludging is longer that 24 months	0.08 l/cap x d
Connection between chambers	Simple wall openings assuring even distribution situated above the highest sludge level and below the lowest level of the scum. For domestic wastewater, the upper part of opening is 30 cm below outlet level and ist bottom is at least half the water depth, above the floor.
SS/COD ratio	Domestic: 0.35-0.55 usually 0.42
Surface load	< 0.6 m^3/m^2 of wastewater peak flow
Height of scum layer	20-30 cm
HRT in settler for DEWATS	2 h
Lenght to width ratio	3:1 to 2:1
Outlet water depth	1.8 m to 2.2 m, normally 1.8 m
1^{st} chamber / 2^{nd} chamber ratio	first chamber is 2/3 of total length
Outlet T-joint	20 cm above and below outlet level
Removal of scum interval	6 months, community toilets 3 months
Manholes	60 cm diameter in every chamber
Construction	Water tight
Ventilation	Extended above roof
Hydraulic gradient between inlet pipe and outlet pipe	15-30 cm

Steps and formulas

Given Parameters:

-Daily wastewater flow (based on actual calculation of water consumption)

-Time of most wastewater flow (based on activities generating wastewater)

-COD_{in} (based on lab test results or per capita calculation)

-$BOD_{5\ in}$ (based on lab test results or per capita calculation)

-Settleable SS/COD ration (based on lab test result or assumption)

Chosen parameters:

-Hydraulic Retention Time (1.5 – 2 hours)

-Desludging interval (24-36 months)

-Surface Load (less than 0,6 m^3/m^2)

-Water depth at outlet (check water table of site condition, 1.8-2.0 m)

-Inner width of septic tank (check area available)

Calculation Factors:

-Factor HRT to COD removal

-Factor efficiency ratio of BOD removal to COD removal

-Factor reduction of sludge volume during storage

Removal of organic pollutants (BOD and COD removal)

1. Determine BOD_{in} and COD_{in}

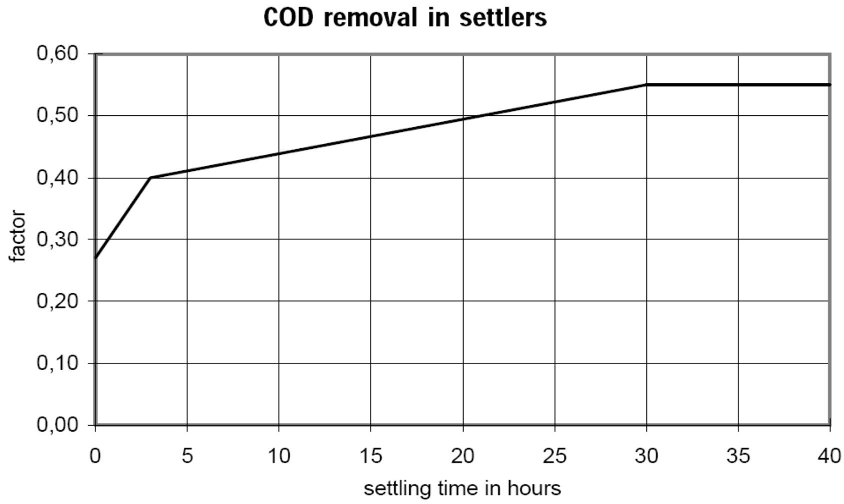
2. Determine max flow at peak hours

$$\max flow\ at\ peak\ hours\ \left(\frac{m^3}{h}\right) = \frac{volume\ of\ wastewater\ (m^3)}{time\ of\ most\ wastewater\ flow\ (h)}$$

3. Determine COD/BOD_{ratio}

$$COD/BOD_{ratio} = \frac{COD_{in}(\frac{mg}{l})}{BOD_{in}(\frac{mg}{l})}$$

4. Determine factor HRT to COD removal



HRT < 1:
factor = HRT*0.3

HRT < 3:
factor = [(HRT-1) *0.1/2] +0.3

HRT < 30:
factor = [(HRT-3) *0.15/27] +0.4

HRT ≥ 30:
factor = 0.58

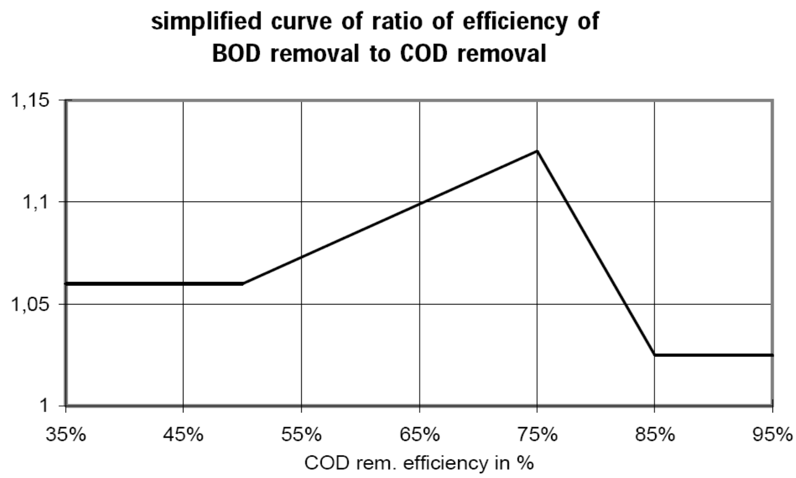
5. Determine COD removal rate (%)

$$COD_{removal\ rate}\ (\%) = \frac{\frac{SS}{COD_{ratio}}}{Surface\ load\ \left(\frac{m^3}{m^2}\right)} \times factorHRT$$

6. Determine COD_{out} $(\frac{mg}{l})$

$$COD_{out}\ (\frac{mg}{l}) = (1 - COD_{removal\ rate}\ (\%)) \times COD_{in}\ (\frac{mg}{l})$$

7. Determine factor efficiency ratio of BOD_5 removal to COD removal.



COD_{rem} < 0.5:
factor = 1.06

COD_{rem} < 0.75:
factor = [(COD_{rem}-0.5) *0.065/0.25] +1.06

COD_{rem} < 0.85:
factor = 1.125-[(COD_{rem}-0.75) *0.1/0.1]

COD_{rem} ≥ 0.85:
factor = 1.025

8. Determine BOD_5 removal rate (%)

$BOD_{5\ removal\ rate\ (\%)}$ = (factor efficiency of BOD_5 removal to COD removal × $COD_{removal\ rate}$ (%))

9. Determine BOD_{5out} $(\frac{mg}{l})$

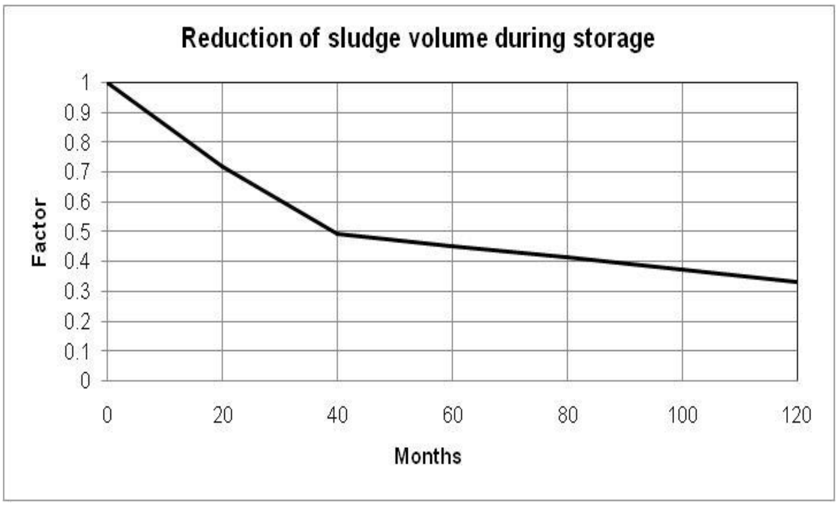
$$BOD_{5out}\left(\frac{mg}{l}\right) = (1 - BOD_{5\ removal\ rate}\ (\%)) \times BOD_{5\ in}\ (\frac{mg}{l})$$

Determination of sludge and storage volume

10. Determine settable SS/$COD_{outflow}$

$$\frac{settable\ SS}{COD_{outflow}} = (\frac{SS}{COD_{ratio}}) \times 0.95$$

11. Determine factor reduction of sludge volume during storage



SRT< 36:
factor = 1-(SRT*0.014)

SRT< 120:
factor = 0.5-(SRT-36) *0.002

SRT≥ 120:
factor = 1/3

12. Determine sludge volume per $BOD_{5\ removal}$ $(\frac{l}{g_{BOD_5}})$

Sludge volume per BOD_5 removal $(\frac{l}{g_{BOD_5}})$ = *factor sludge reduction (%) × sludge volume(TTR)* $(\frac{l}{g_{BOD_5\ removal}})$

13. Determine sludge volume (m^3)

$BOD\ reduction\ (\frac{g}{m^3}) = BOD_{5\ in}\ (\frac{g}{m^3}) - BOD_{5\ out}\ (\frac{g}{m^3})$

$Sludge\ volume\ from\ BOD\ reduction\ (m^3/m^3) = Sludge\ volume\ per\ BOD\ removal\ (\frac{l}{g\ BOD_{removal}}) \times BOD\ reduction\ (\frac{g}{m^3})$

$Sludge\ Volume\ (m^3) = Sludge\ volume\ from\ BOD\ reduction\ (m^3/m^3) \times wastewater\ flow\ \left(\frac{m^3}{d}\right) \times desluging\ intervals\ (months) \times 30\ (days)$

14. Determine water volume (m^3)

$$water\ volume\ (m^3) = HRT(h) \times \max\ flow\ at\ peak\ hours\ (\frac{m^3}{h})$$

15. Determine minimum settler surface (m^2)

$$min\ settler\ surface\ (m^2) = \frac{\max\ flow_{\ peak\ hours}\ (\frac{m^3}{h})}{surface\ loding\ \left(\frac{m^3}{m^2}\right)}$$

Checking criteria: the area has to be bigger than this!

16. Determine volume of ST (m^3)

$$volume\ of\ ST\ (m^3) = sludge\ volume (m^3) +\ water\ volume (m^3)$$

17. Determine required 1st chamber inner length (m).

$$required\ chamber\ inner\ length (m) = \frac{\frac{2}{3} \times volume\ of ST}{chosen\ inner\ width\ \times chosen\ water\ depth}$$

18. Determine 1st chamber inner length (m).

Round up the number to a practical length!

19. Determine required 2nd chamber inner length (m).

$$required\ 2\ ^{nd}\ chamber\ inner\ lenght\ (m) = \frac{required\ 1^{st}\ chamber\ inner\ lenght\ (m)}{2}$$

20. Determine 2nd chamber inner length (m)

Round up the number to a practical length!

21. Determine area (m^2)

$$area (m^2) = width (m) \times inner\ lenght\ (m)$$

Check!!! Actual area > minimum settler surface!!!

22. Determine actual volume of settler (m^3).

$$actual\ volume\ of\ settler\ (m^3) =\ area (m^2) \times water\ depth\ (m)$$

<u>Determination of Biogas Production</u>

23. Determine Biogas production ($\frac{m^3}{day}$)

$$COD\ reduction\ \left(\frac{g}{m^3}\right) =\ COD_{in}\ \left(\frac{g}{m^3}\right) -\ COD_{out}\ \left(\frac{g}{m^3}\right)$$

$$Convert\ COD\ reduction\ to\ \left(\frac{kg}{m^3}\right)$$
$$= COD\ reduction\ \left(\frac{g}{m^3}\right) \times wastewater\ flow\ (m^3)$$
$$\times CH_4\ produced\ per\ kg\ COD_{removal}\ \left(\frac{m^3}{kg}\right)$$

$$CH_4 \text{produced per kg COD}_{\text{removal}} = \frac{0{,}35\ \text{m}^3 \text{Biogas}}{\text{kg COD}_{\text{removal}}}$$

Since Biogas is composed by CH_4=70%, CO_2 + H_2S = 30%, then the total Biogas produced is:

$$Biogas\ Produced\ (m^3) = \frac{\mathrm{CH_4\ produced\ (m^3)}}{0{,}7}$$

Determine Biogas dissolved, knowing that 50% of the Biogas is dissolved and we cannot use it, so it is only 50% which can be burned:

$$Biogas\ dissolved\ (m^3) = \ Biogas\ produced\ (m^3)\ \times 0{,}5$$

Needed Parameters for design

For the design of the AS, it is important to have the following information:

-Inflow, Q $\left(\frac{m^3}{d}\right)$

-Time of most flow (peak hour), t_{pf} (h)

-Peak flow, $Q_{pf} = \frac{Q}{t_{pf}}$

-BOD_{in} $\left(\frac{mg}{l}\right)$

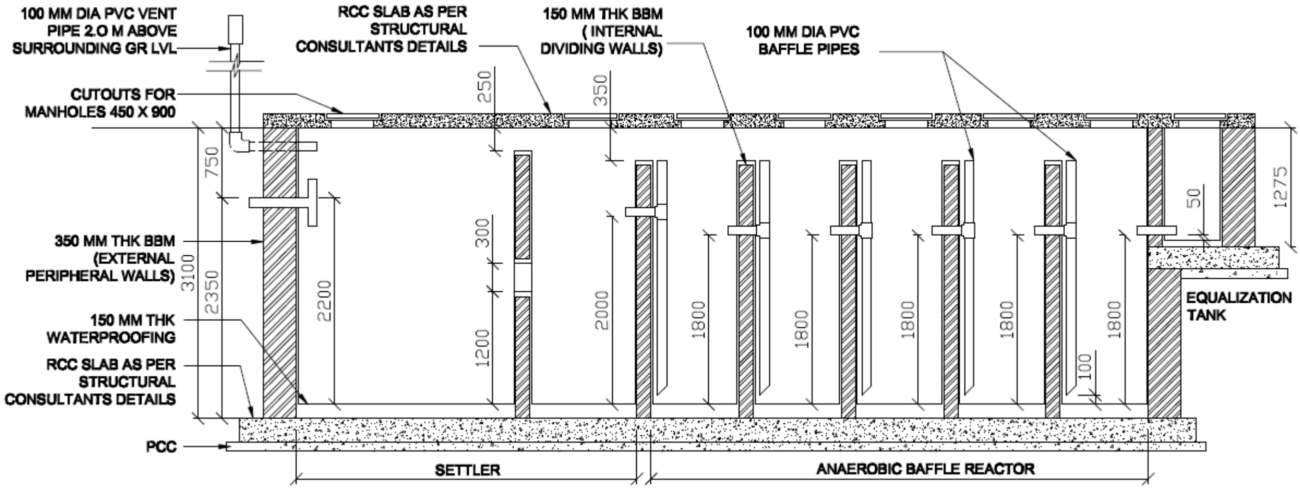
-COD_{in} $\left(\frac{mg}{l}\right)$

-Inlet point, distance of the inlet point (m) from the surface. This depends on the position of the already existing septic tanks and the pipe system.

Designing an Anaerobic Baffle Reactor (ABR)

Baffle reactor tanks are underground or closed tanks with four to eight chambers in series, which are designed to take care of the required hydraulic and organic loadings.

The length and the width (area= Q/v) required for each chamber is derived from the peak hour flow and the velocity of the wastewater within the chamber.



By means of the baffles, the water is forced to come in contact with the anaerobic bacteria which lives in the sludge located at the bottom of the thanks. Some turbulence is needed, but if the up velocity is too high, the water will pass through too quick reducing the efficiency of the treatment and flushing out the bacteria.

The efficiency of an ABR increases with higher organic load. The hydraulic gradient between inlet and final outlet should be in the range of 15 to 30 cm. Usually a distribution channel or baffle is needed to distribute the water in a uniform way in the chambers. If the W is higher than 2m, is better to construct support walls in between. A baffle wall will reduce the velocity.

Rules of thumb during design

Sludge volume	20 l /cap
Sludge storage volume	4 l /m³ BOD inflow in the settler. 1.4 l/ m³ BOD removed in the up-flow tank.
SS/COD ratio	Domestic: 0.35 – 0.55
Scum volume	10 l/ cap
Hydralic Retention Time	Not less than 8 hours, better between 12-14 hours for the whole system Above 20 hrs retention time, reduction is very minimal and not any more economically viable. 20 hours would be the optimum.
Lenght of chambers	Ideal lengths are taken as 0.70 to 0.85 m.
Depth of chambers	1.8m – 2.2m (Outlet water depth)

Width of chambers	This is actually the parameter we play with, so it can be from 1-2 mts till … many meters
Lenght to hight ratio	0.4 to 0.5
Distance between pipes	Should not exceed 30cm
Number of chambers	At least 4 chambers, no more than 8
Up-flow velocity	0.9 to 1.2 m/h, this is the most crucial parameter for dimensioning with high hydraulic loading. When the velocity is low, the the system is bigger and expensive. If the velocity is higher then it flushes out the bacteria.
Organic load	< 6 $kg/m^3 \times day$ BOD
BOD removal rate	70 – 95 %
COD removal rate	65 - 90 %
Temperature	The higher the T, the better the process. More than 25°C is optimum.
Distance between baffle pipes	15 – 20 cm, up to 30 cm (double of diameter of the pipes)

Steps and formulas

Given Parameters:

-Daily wastewater flow

-Time of most wastewater flow

-COD_{in} (based on COD_{out} of AS)

-$BOD_{5\ in}$ (based on $BOD_{5\ out}$ of AS)

-SS/COD ration (based on assumption)

-Lowest temperature

Chosen parameters:

-Water depth at outlet (check water table of site condition and up-flow velocity during calculation)

-Up-flow velocity

Calculation Factors:

-Factor organic load

-Factor strength

-Factor temperature

-Factor chambers

-Factor HRT

-Factor efficiency ratio of BOD removal to COD removal

Determination of chambers sizes and number

1. Determine BOD_{in} and COD_{in} (outlet Anaerobic Settler)

2. Determine max flow at peak hour

$$\max flow\ at\ peak\ hours\left(\frac{m^3}{h}\right)=\frac{volume\ of\ wastewater\ (m^3)}{time\ of\ most\ wastewater\ flow\ (h)}$$

3. Determine required max. length of chamber (m):

$$requiered\ max.lenght\ of\ chamber(m)=\ water\ depth\ at\ outlet\ (m)\times 0.4\ (length\ to\ height\ ratio)$$

(water depth is usually taken as 1,8 m)

4. Determine required min. width of chamber (m)

$$\text{required min. width of chamber (m)}=\frac{max.peak\ flow\ (\frac{m^3}{h})}{upflow\ velocity\ \left(\frac{m}{h}\right)\times length\ of\ chamber(m)}$$

5. Determine actual up-flow velocity $(\frac{m}{h})$

$$\text{actual up flow velocity}\left(\frac{m}{h}\right)=\frac{max.peak\ flow\ (\frac{m^3}{h})}{actual\ lenght\ (m)\times actual\ width\ (m)}$$

Check actual up-flow velocity is best below 1 $\frac{m}{h}$!!!

If up-flow velocity is above 1 $\frac{m}{h}$, adjust width and length!!!

It can go up to 1,2 but it is not recommended

6. Determine number of chambers

Just pick a number of chambers.

Check!!! Minimum no. of chambers is 4 and maximum is 8!!!

7. Determine actual volume of ABR (m^3)

$$\text{actual volume of ABR }(\mathrm{m^3})=\ \text{lenght (m)}\times\text{width (m)}\times\text{depth (m)}\times\text{number of chambers}$$

8. Determine sludge volume (m^3)

$$\text{sludge volume }(\mathrm{m^3})=5\%\ \times\ \text{actual volume of ABR }(\mathrm{m^3})$$

9. Determine water volume (m^3)

$$\text{water volume }(\mathrm{m^3})=\ \text{actual volume of ABR }(\mathrm{m^3})-\text{sludge volume }(\mathrm{m^3})$$

10. Determine HRT (h)

$$\text{HRT (h)}=\frac{\text{water volume of ABR }(\mathrm{m^3})}{\text{daily wastwater flow}(\frac{\mathrm{m^3}}{\mathrm{d}})}\times\frac{24\ h}{1\ d}$$

Check!!! HRT should be below 20 hrs for an economically-viable treatment!!!

Prioritize actual up-flow velocity!!!

If the HRT is less than 12 hours or more than 20 hours, then you need to refine and assume a new number of chambers.

<u>Removal of organic pollutants (BOD & COD removal)</u>

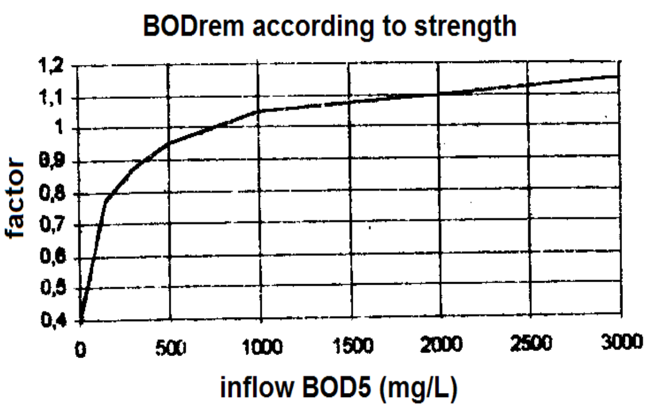
11. Determine organic load BOD$(\frac{kg}{m^3 \times day})$

$$\text{organic load BOD }(\frac{kg}{m^3 \times day}) = BOD_{in}\left(\frac{g}{m^3}\right) \times \frac{\max peak\ flow\ per\ hour\left(\frac{m^3}{h}\right)}{actual\ volume\ of\ ARB\ (m^3)} \times \frac{24\ h}{1\ day} \times \frac{1\ kg}{1000\ g}$$

Check!!! Organic load < $\frac{6\ kg}{m^3}$ × day BOD!!!

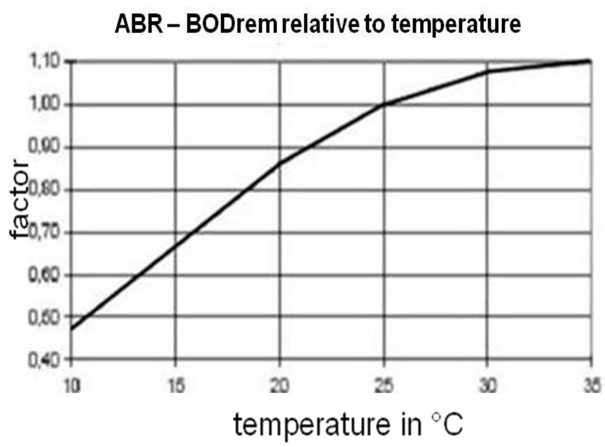
It should be about 1,5 to 2 for domestic wastewater

12. Determine Factor strength.



BOD_{in} < 150 mg/L: factor = BOD_{in}*0.37/150+0.4
BOD_{in} < 300 mg/L: factor = (BOD_{in} -150) *0.1/150+0.77
BOD_{in} < 500 mg/L: factor = (BOD_{in} -300) *0.08/200+0.87
BOD_{in} < 1000 mg/L: factor = (BOD_{in} -500) *0.1/500+0.95
BOD_{in} < 3000 mg/L: factor = (BOD_{in} -1000) *0.1/2000+1.05
BOD_{in} ≥ 3000 mg/L: factor = 1.15

13. Determine Factor temperature



Temp < 20° C: Factor= (temp-10) *0.3 9 /20+ 0.47

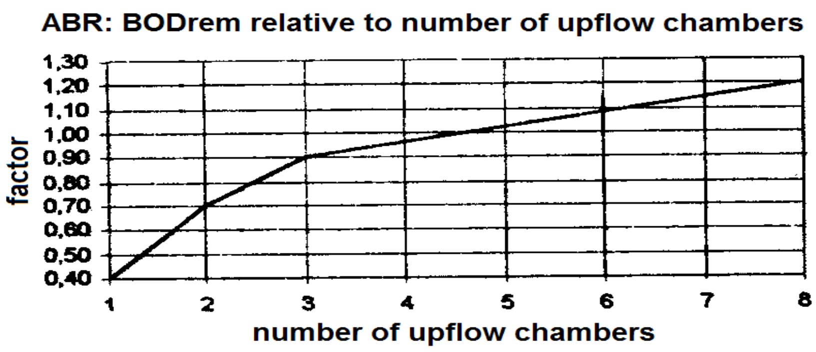
Temp < 25° C: Factor= (temp-20) *0.14/5+ 0.86

Temp < 30° C: Factor= (temp-25) *0.08/5+1.0

Temp < 35° C: Factor= (temp-30) *0.06/5+1.08

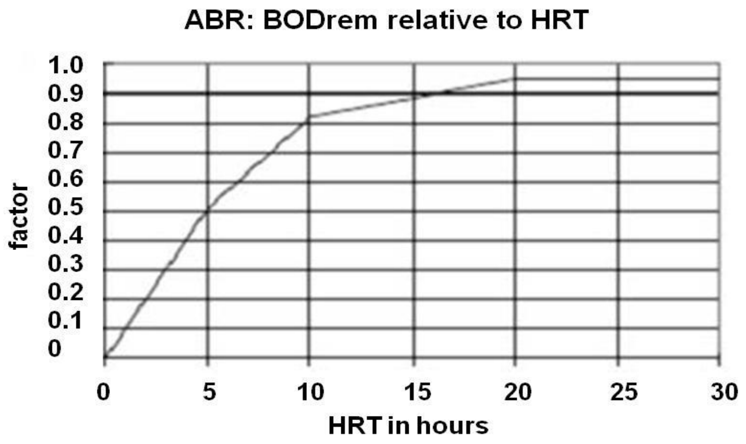
Temp ≥ 35° C: Factor= 1.1

14. Determine factor no. of chambers



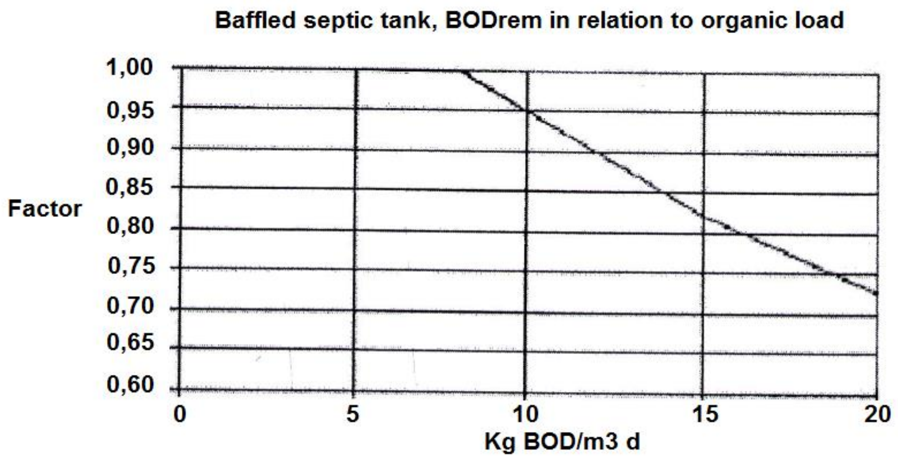
no = 1:
factor =0.4
no = 2:
factor =0.7
no = 3:
factor =0.9
no > 3:
factor =(no-3) *0.06+0.9

15. Determine factor HRT



HRT < 5h
Factor = HRT*0.5/5
HRT < 10h
Factor = [(HRT-5)*0.32/5] + 0.5
HRT < 20h
Factor =[(HRT-10)*0.13/10] + 0.82
HRT > 20h
Factor = 0.95

16. Determine factor organic load



17. Determine BOD $_{\text{removal rate}}$ by factors (%)

$$\mathrm{BOD}_{\text{removal rate by factors}}\ (\%) = \text{factor strengh} \times \text{factor temperature} \times \text{factor HRT} \times \text{factor no. chambers} \times \text{factor organic load}$$

(Determine Applied BOD Removal Rate)

18. Determine $\mathrm{BOD}_{5\,\text{out}}\left(\frac{mg}{l}\right)$

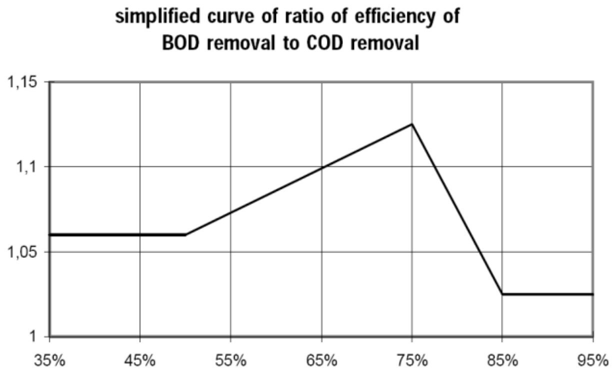
$$\mathrm{BOD}_{5\text{out}}\left(\frac{mg}{l}\right) = (1 - BOD_{removal\ rate\ by\ factor}) \times \mathrm{BOD}_{5\text{ in}}\left(\frac{mg}{l}\right)$$

19. Determine total BOD $_{\text{removal rate}}$ (%):

$$total\ BOD_{removal\ rate}\ (\%) = 1 - \frac{BOD_{out}\ (\frac{mg}{l})}{BOD_{in}(\frac{mg}{l})}$$

Check!!! Total BOD removal rate & BOD removal rate by factor
Now you have to compare which one is higher, and this is the removal rate we assume!

20. Determine factor efficiency BOD removal rate by COD removal.



BOD_{rem}<0.5: factor = 1.06

BOD_{rem}<0.75: factor = (BOD_{rem}-0.5) *0.065/0.25 +1.06

BOD_{rem}<0.85: factor = [1.125-(BOD_{rem}-0.75) *0.1] +0.1

BOD_{rem} ≥ 0.85: factor = 1.025

BOD_{rem} = COD_{rem} * factor

COD_{rem} = BOD_{rem} factor

21. Determine Total COD removal rate (%)

$$Total\ COD_{removal\ Rate}(\%) = \frac{Total\ BOD\ removal\ rate}{Factor\ efficiency\ BOD\ removal\ to\ COD\ removal}$$

22. Determine COD_{outlet}

$$COD_{outlet} = (1 - total\ COD_{removal\ rate}) \times COD_{in}\ (\frac{mg}{l})$$

Biogas production calculation

23. Determine Biogas production ($\frac{m^3}{day}$)

$$COD\ reduction\ \left(\frac{g}{m^3}\right) = COD_{in}\left(\frac{g}{m^3}\right) - COD_{out}\left(\frac{g}{m^3}\right)$$

$$Convert\ COD\ reduction\ to\ \frac{kg}{m^3} = COD\ reduction\ \left(\frac{g}{m^3}\right) \times \frac{1\ kg}{1000\ g}$$

$$CH_4\ produced = COD\ reduction\ \left(\frac{g}{m^3}\right) \times wastewater\ flow\ (m^3)$$

$$\times CH_4\ produced\ per\ kg\ COD_{removal}\left(\frac{m^3}{kg}\right)$$

$$Biogas\ produced\ (m^3);\ considering\ that\ the\ contents\ are\ CH_4 = 70\%, CO_2 + H_2S = 30\%$$

$$Biogas\ produced\ (m^3) = \frac{CH_4\ produced\ (m^3)}{0{,}7}$$

$$Biogas\ dissolved\ (m^3) = Biogas\ produced\ (m^3) \times 0{,}5$$

Needed Parameters for design

For the design of the ABR, it is important to have the following information:

-Inflow, Q $\left(\frac{m^3}{d}\right)$

-Time of most flow (peak hour), t_{pf} (h)

-Peak flow, $Q_{pf} = \frac{Q}{t_{pf}}$

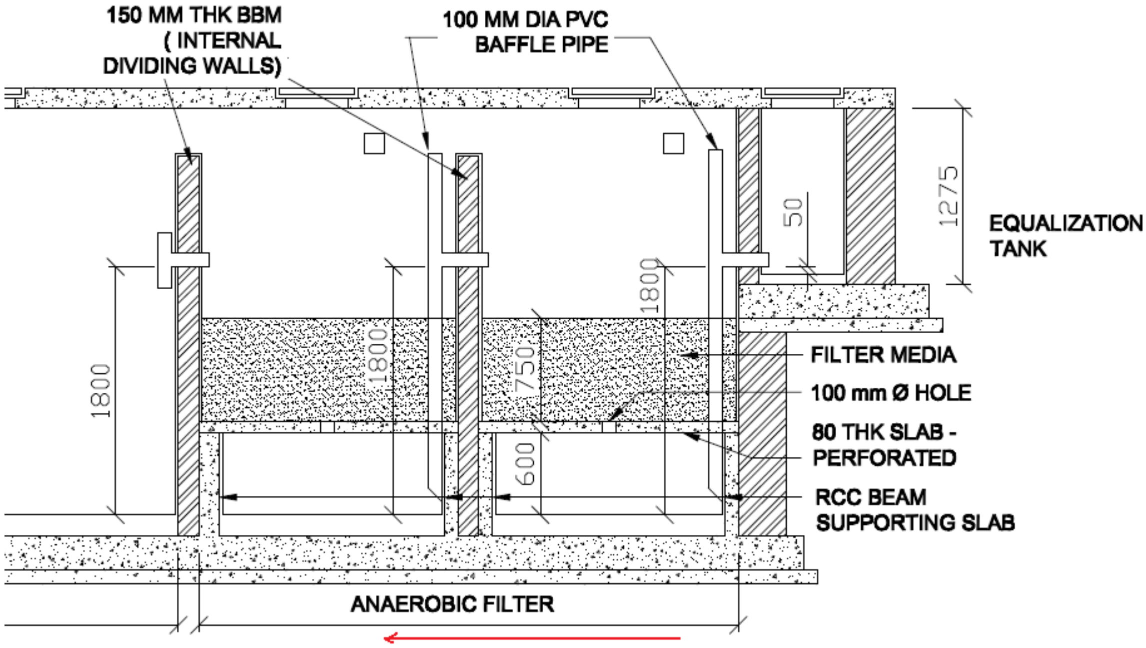
-BOD_{in} $\left(\frac{mg}{l}\right)$

-COD_{in} $\left(\frac{mg}{l}\right)$

-Inlet point, distance of the inlet point (m) from the surface. This depends on the position of the already existing septic tanks and the pipe system.

Designing an Anaerobic Filter (AF)

Anaerobic Filter tanks are underground or closed tanks with two to four chambers in series. The anaerobic filter, also known as fixes bed or fixed film reactor, includes the treatment of non-settle able and dissolved solids by bringing them in close contact with a surplus of active bacterial mass.



Filter material, such as gravel, rocks, cinder or specially formed plastic pieces provide additional surface area for bacteria to settle and grow. In fact, anything that can give more surface to the bacteria to grow will do. The fresh wastewater is forced to come in contact with active bacteria intensively. Actually, the larger the surface provided for bacterial growth, the quicker the digestion.

Anaerobic Filter Tanks are not always included in the design of a DTS. One option could be to design the two last chambers of the ABR with a support and perforated support and RCC perforated slab. In case the efficiency of the whole system is not enough or the inlet BOD is higher as it was predicted, the two chambers can be filled in with the filter material.

The length and width required for each of the chambers is derived from the peak hour flow and defined velocity of wastewater within the chamber. Anaerobic filters may be operated as down flow or up flow systems. The up-flow system is normally preferred and used as the risk of washing out active bacteria is less in this case.

An important design criterion is that of equal distribution of wastewater upon the filter area. The baffle walls or pipes (down shaft pipes) ensure the direction of wastewater flow within the tank; it forces the wastewater to flow through the filter media in each of the chamber.

Rules of thumb during design

SS/COD ratio	Domestic : 0.35 – 0.45
Hydraulic Retention Time	24 – 48 hrs
Specific surface of filter medium	80 – 120 m^2/m^3
Voids in filter mass	30 – 45%
Size of filter	5 – 15cm diameter cinder 5 -10cm diameter rock
Up-flow velocity	Max 2 m/h The up-flow velocity in the anaerobic filter is mainly governed by: • Quantity of wastewater • Voids in the filter material
Organic load	<4 kg COD/m^3 × day
Outlet water depth	1.8 m – 2.2 m

Steps and formulas

Determination of Chamber size and numbers

1. Determine BOD_{in} and COD_{in} (outlet ABR)

2. Determine max peak flow per hour $\left(\frac{m^3}{h}\right)$:

$$\max peak\ flow\ per\ hours\ \left(\frac{m^3}{h}\right) = \frac{volume\ of\ wastewater\ (m^3)}{time\ of\ wastewater\ flow\ (h)}$$

3. Determine filter height (m):

$$filter\ height\ (m) = depth\ of\ filter\ tank\ (m) - 0.6(m) - 0.4(m) - 0.05(m)$$

4. Determine no. of chamber:

Minimum number of chambers 1 or 2. Additional chambers can be added according to the requirement of outlet wastewater quality

5. Determine HRT inside AF reactor (h);

$$\begin{aligned}\text{HRT inside AF reactor(h)} &= \{depth\ of filter\ tank\ (m) \\ &- [filter\ height\ (m) \times (1 - \text{voids in filter mass})]\} \times \text{lenght of each tank(m)} \\ &\times \text{width of the filter tank(m)} \times \frac{\text{number of filter tank}}{daily\ wastwater\ flow\ \frac{m^3}{24\ h}}\end{aligned}$$

Check!!! As a standalone treatment, normal HRT in AF is 24 – 48 hrs !!!

6. Determine max velocity in filter voids $(\frac{m}{h})$:

$$\text{max velocity in filter voids}\left(\frac{m}{h}\right) = \frac{\max peak\ flow\ per\ hours \left(\frac{m^3}{h}\right)}{\text{width of the filter tank(m)} \times \text{voids in filter mass (\%)} \times \text{lenght of each tank(m)}}$$

7. Determine net volume of filter tank (m³):

$$\text{net volume of filter tank (m3)} = \text{lenght of each tank(m)} \times \text{width of the filter tank(m)} \times \text{number of filter tank.} \times \{depth\ of filter\ tank\ (m) - [\text{filter height (m)} \times (1 - \text{ voids in filter mass (\%)})]\}$$

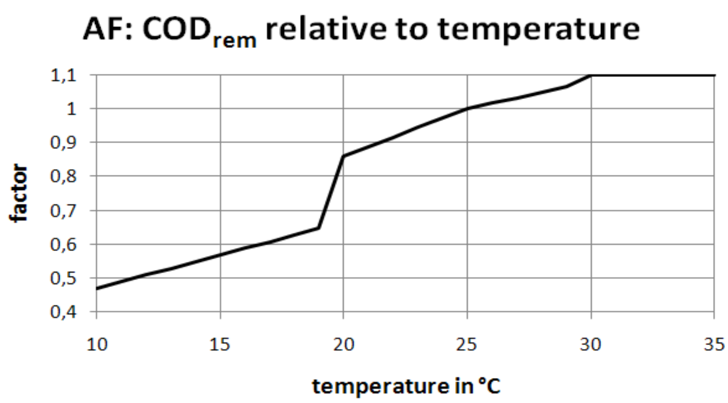
Removal of organic pollutants (BOD and COD removal)

8. Determine organic load of AF COD($\frac{kg}{m^3} \times day$):

$$\text{organic load of AF COD}\left(\frac{kg}{m^3} \times day\right) = volume\ of\ wastewater\ (m^3) \times \frac{\text{COD}_{\text{in}} \frac{\text{mg}}{\text{l}}}{\text{net volume of filter tank } [m^3]} \times \left(\frac{1}{1000}\right)$$

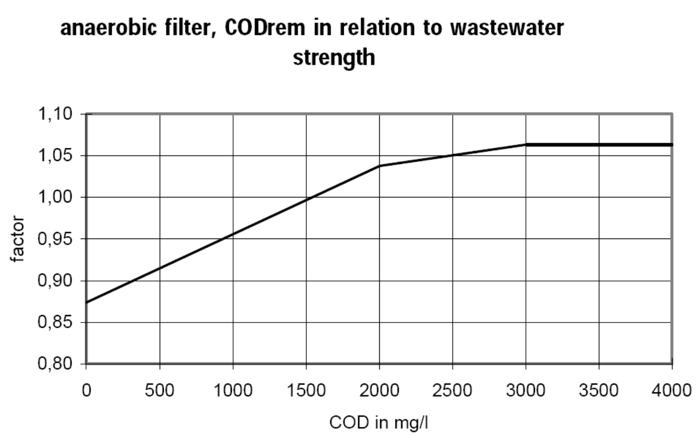
Check!!!Organic load < 4 kg COD/ m³/day!!!

9. Determine factor temperature:



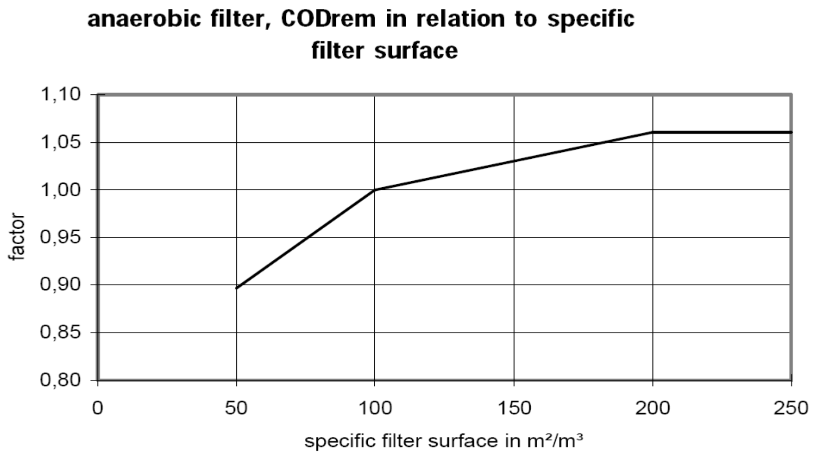
temp < 20 °C:
factor = (temp-10) *0.39/20+0.47
temp < 25 °C:
factor = (temp-20) *0.14/5+0.86
temp < 30 °C:
factor = (temp-25) *0.08/5+1
temp ≥ 30 °C:
factor = 1.10

10. Determine factor strength:



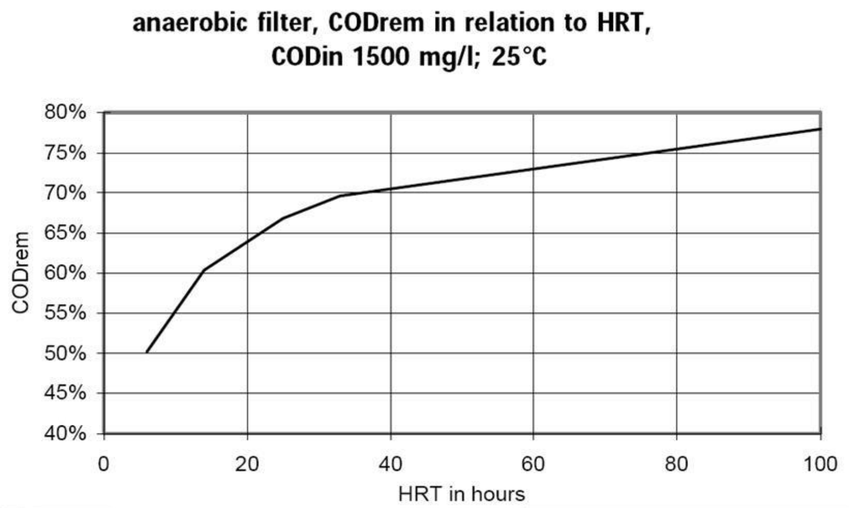
COD_{in} < 2000 mg/L:
factor =([COD_{in}*0.17]/2000) +0.87
COD_{in} < 3000 mg/L:
factor = ([COD_{in} – (2000*0.02)]/1000) +1.04
COD_{in} ≥ 3000 mg/L:
factor = 1.06

11. Determine factor surface:



surface < 100 m^2/m^3:
factor = [((surface-50) *0.1)/50] +0.9
surface < 200 m^2/m^3:
factor = [(surface-100) *0.06]/100+1
surface ≥ 200 m^2/m^3:
factor = 1.06

12. Determine factor HRT:



HRT < 12h:
factor = HRT*0.16/12+0.44

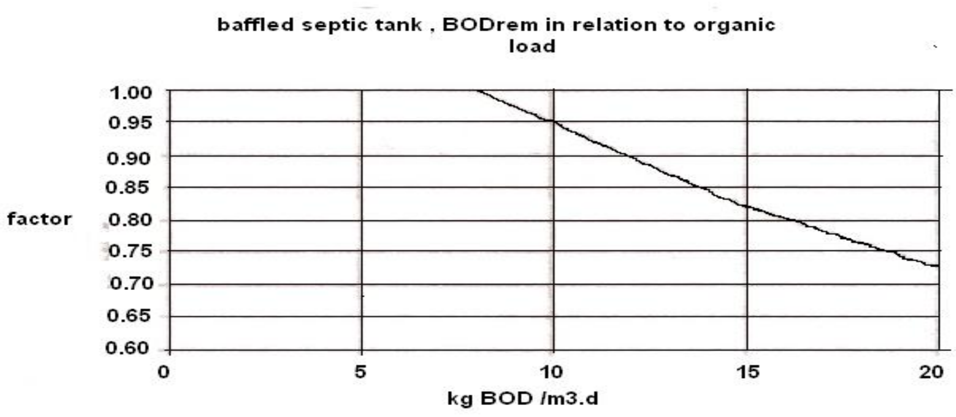
HRT < 24h:
factor = *(*HRT-12)*0.07/12+0.6

HRT < 33h:
factor = *(*HRT-24)*0.03/9+0.67

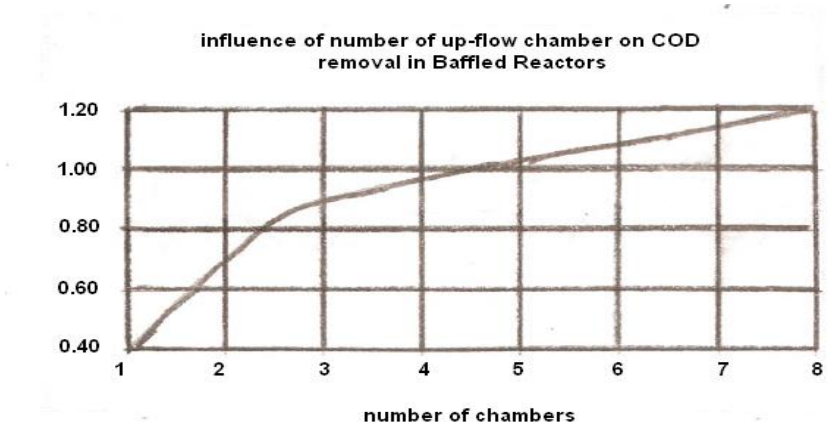
HRT < 100h:
factor = *(*HRT-33)*0.09/67+0.7

HRT ≥ 100h:
factor = 0.78

13. Determine factor organic load:



14. Determine factor chamber.



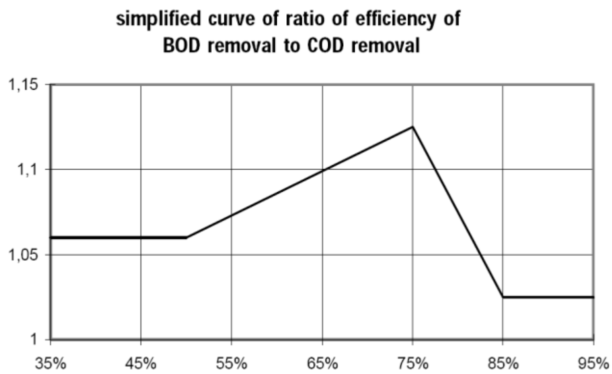
15. Determine COD $_{\text{removal rate (\%)}}$:

$$\text{COD}_{\text{ removal rate (\%)}} = (\text{factor temperature } \times \text{factor strength } \times \text{factor surface } \times \text{ factor HTR } \times \text{ factor organic load } \times \text{factor chamber})$$

16. Determine COD $_{\text{outlet}}$ $(\frac{mg}{l})$:

$$\text{COD}_{\text{outlet}} \left(\frac{mg}{l}\right) = (1 - \text{COD}_{\text{removal rate}}) \times \text{COD}_{\text{in}} \left(\frac{\text{mg}}{\text{l}}\right)$$

17. Determine factor efficiency BOD $_{\text{removal}}$ to COD $_{\text{removal}}$:



BOD_{rem}<0.5: factor = 1.06

BOD_{rem}<0.75: factor = (BOD_{rem}-0.5) *0.065/0.25 +1.06

BOD_{rem}<0.85: factor = [1.125-(BOD_{rem}-0.75) *0.1] +0.1

BOD_{rem} ≥ 0.85: factor = 1.025

BOD_{rem} = COD_{rem} * factor

COD_{rem} = BOD_{rem} factor

18. Determine $BOD_{removal\ rate}$:

$$BOD_{removal\ rate} = \text{COD}_{\text{ removal rate}} \times \text{factor efficiency BOD removal to COD removal}$$

19. Determine BOD $_{\text{outlet}}$:

$$\text{BOD outlet} = (1 - \text{BOD}_{\text{removal rate}}) \times \text{BOD}_{\text{ in}} \left(\frac{\text{mg}}{\text{l}}\right)$$

Biogas production calculation

20. Determine Biogas production ($\frac{m^3}{day}$) =

COD reduction ($\frac{g}{m^3}$)=COD_{in} $\left(\frac{g}{m^3}\right)$ – COD_{out} $\left(\frac{g}{m^3}\right)$

$$convert\ COD\ reduction\ to\ \left(\frac{kg}{m^3}\right) = COD\ reduction\ \left(\frac{g}{m^3}\right) \times \frac{1\ m^3}{1000\ g}$$

Determine CH_4 produced = $convert\ COD\ reduction\ to\ \left(\frac{kg}{m^3}\right) = COD\ reduction\ \left(\frac{g}{m^3}\right) \times wastewater\ flow\ (m^3) \times CH_4\ produced\ per\ kg\ COD_{removal}\ \left(\frac{m^3}{kg}\right)$

$$Biogas\ produced\ (m^3);\ CH_4 = 70\%\ , CO_2 + H_2S = 30\% = \frac{CH_4\ produced\ (m^3)}{0.7}$$

$$Biogas\ dissolved\ (m^3)\ ; 50\%\ dissolved = Biogas\ produced\ (m^3)\ \times 0.5$$

Group Work:
Design of Constructed Wetlands

Methodology

Designing a Horizontal Gravel Filter Plant (HGFP)

Planted gravel filter tanks (also referred to as wetlands) are over ground shallow open tanks filled with graded filter material (substrate). Usually river pebbles or constriction gravel are used as filter material and planted with vegetation. The wastewater introduced into the tanks flows through the substrate and is discharged out of the tank through the structure which controls the depth of wastewater in the filter tank.

There are mainly two types of flow (subsurface) directions in the wetlands: horizontal flow and vertical flow. Under DEWATS principles only horizontal flow wetland is considered. Due to its horizontal flow direction, the wetland is also known as horizontal planted gravel filter (HPGF). During the water flow through the filter media, wastewater will come in contact with a network of aerobic, anoxic and anaerobic zones.

Attached and suspended microbial growth is responsible for the removal of soluble organic compounds, which are degraded biologically both aerobically and anaerobically. The oxygen required for aerobic degradation is supplied directly from the atmosphere by diffusion or oxygen leakage from the vegetation roots.

The quality of treatment in well operated plated gravel filters is in the range of 50% to 60% BOD removal. Furthermore, in this step there is enrichment of dissolved oxygen in a large extent. It is used for removal of odour, colour and for hygenisation rather than for removal of organic pollutants.

PGF are suitable for domestic wastewater which has a lower content of suspended solids, but pre-treatment is necessary to eliminate solids of larger size before they are allowed to enter the filter.

Rules of thumb

Hydraulic load limit	100 l/m^2
Organic load limit	10 g BOD/ m^2
Voids of Gravel	35% – 45%
Size of Gravel	5-7mm, 10-12mm, 50-70mm, diameter of gravel
Slope	1%
Height of Filter	50 - 60cm
Construction	Swivel at inlet and outlet cross section to adjest water level

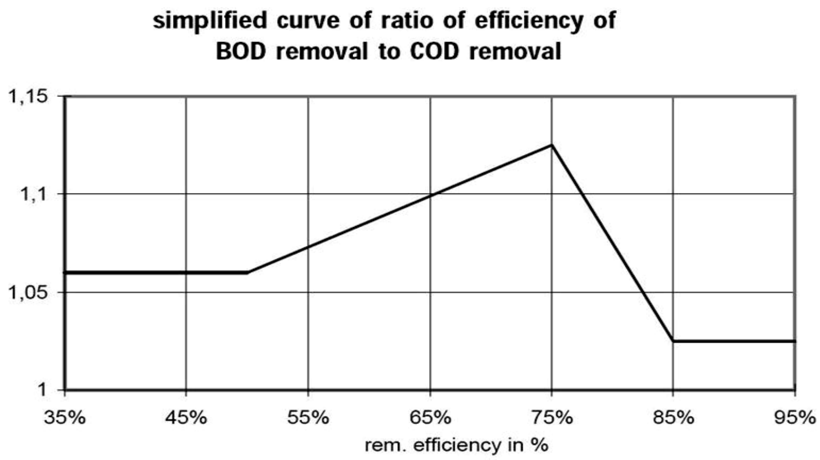
Calculation.

1. Determine $\frac{COD}{BOD}\ ratio = \frac{\mathrm{COD}_{\mathrm{in}\,\frac{mg}{l}}}{\mathrm{BOD}_{\mathrm{in}\,\frac{mg}{l}}}$

2. Determine BOD removal rate (%):

$$\mathrm{BOD}_{\text{removal rate}}\ (\%) = \frac{\mathrm{BOD}_{\mathrm{in}(\frac{mg}{l})} - expected\ BOD_{out(\frac{mg}{l})}}{\mathrm{BOD}_{\mathrm{in}\,\frac{mg}{l}}}$$

3. Determine factor efficiency ratio of BOD removal to COD removal



Removal < 0.5:
factor = *1.06*

Removal < 0.75:
factor = $(\mathrm{BOD}_{rem}-0.5)*0.065/0.25+1.06$

Removal < 0.85:
factor = $1.125-(\mathrm{BOD}_{rem}-0.75)*0.1/0.1$

Removal ≥ 0.85:
factor = *1.025*

4.Determine COD removal rate (%):

$$\text{COD removal rate } (\%) = \frac{\mathrm{BOD}\ _{\text{removal rate}}}{\text{factor efficiency ratio of }\ \mathrm{BOD}_{\text{removal}}\ \text{ to }\mathrm{COD}_{\text{removal}}}$$

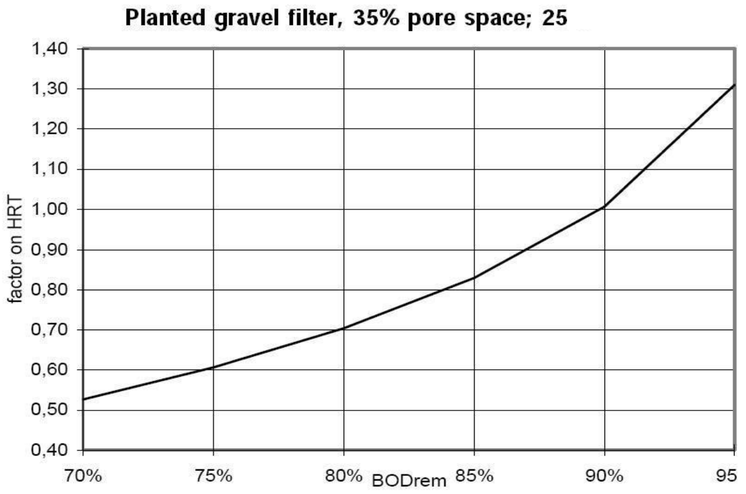
5. Determine COD out ($\frac{mg}{l}$):

$$\mathrm{COD}_{\mathrm{in}\,(\frac{mg}{l})} \times 1 - \mathrm{COD}_{\text{removal rate}}\ (\%)$$

6. Determine Hydraulic Conductivity ($\frac{m}{s}$) :

$$\text{Hydraulic Conductivity}\left(\frac{m}{s}\right) = \left(\frac{Hydraulic\ Conductivity\left(\frac{m}{d}\right)}{86400}\right)$$

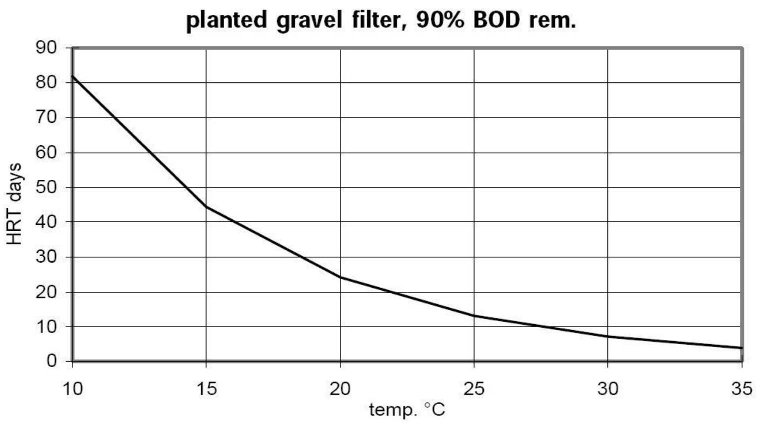
7. Determine factor HRT – BOD removal.



BOD_{rem} < 40%:
factor = BOD_{rem} * 0.22/0.4
BOD_{rem} < 75%:
factor =[((BOD_{rem}-0.4) *31)/35] +0.22
BOD_{rem} < 80%:
factor = [((BOD_{rem}-0.75) *9.5)/5] +0.605
BOD_{rem} < 85%:
factor = [((BOD_{rem}-0.8) *12.5)/5] +0.7
BOD_{rem} < 90%:
factor = [((BOD_{rem}-0.85) *17.5]/5] +0.825
BOD_{rem} ≥ 90%:
factor = [((BOD_{rem}-0.9) *30)/5]+1

Check!!! If it is not specified in chart ……. Check below!!!

8. Determine factor HRT – Temperature.



temp < 15°C:
factor = 82-[(temp-10) *37]/5
temp < 20°C:
factor = 45-[(temp-15) *31]/5
temp < 25°C:
factor = 24-[(temp-20) *11]/5
temp < 30°C:
factor = 13-[(temp-25) *6]/5
temp ≥ 30°C:
factor = 7

9. Determine HRT(d):

$$\text{HRT (d)} = \text{factor HRT to BOD}_{\text{remoal}} \times \text{factor HRT to Temperature}$$

10. Determine HRT in 35% pore space (d):

$$\text{HRT in 35\% pore space (d)} = 35\% \times \text{HRT}$$

11. Determine cross section area 1(m²): (Option 1)

$$\text{cross section area } 1(m^2) = \frac{\text{daily wastwater flow } (\text{m}^3)}{Conductivity\left(\frac{m}{d}\right) \times \text{elevaion } (\%)}$$

12. Determine cross section area 2(m²):

$$\text{cross section area } 2(\text{m2}) = \frac{\text{daily wastwater flow } (\text{m}^3) \times \text{BOD}_{\text{in}} \left(\frac{\text{mg}}{\text{l}}\right)}{\text{max BOD}_5 \text{ on cross section area } (\frac{g}{m^2})}$$

13. Determine chosen cross section area:

14. Determine required width of filter basin (m):

$$\text{required width of filter basin (m)} = \frac{\text{cross section area } (m^2)}{\text{depth (m)}}$$

15. Determine chosen width of filter basin (m):

16. Determine required surface area 1 (m^2):

$$\text{required surface area } 1(\mathrm{m}^2) = \text{ daily flow } (\mathrm{m}^3\ ) \times \frac{\mathrm{BOD_{in}}\left(\frac{\mathrm{mg}}{\mathrm{l}}\right) - \text{expected } \mathrm{BOD_{out}}\left(\frac{\mathrm{mg}}{\mathrm{l}}\right)}{\text{max organic load } (\frac{g}{m^2})}$$

17. Determine required surface area 2 (m^2):

$$\text{required surface area } 1(\mathrm{m}^2) = \frac{\text{daily flow } (\mathrm{m}^3\ ) \times \mathrm{HRT\ (d)}}{\text{depth of filter(m)}}$$

18. Determine required surface area (m^2):

If required surface area 1> required surface area 2 then 1. If required surface area 1 < required surface area 2 then 2!!!

19.Determine required length filter of basin (m):

$$\text{required length filter of basin (m)} = \frac{\text{chosen surface area(} \mathrm{m}^2\text{)}}{\text{width of filter basin (m)}}$$

20. Determine chosen length filter of basin (m).

21. Determine actual surface area (m):

$$chosen\ lenght\ (m) \times\ chosen\ width\ (m)$$

Check!!! Actual surface area > chosen required surface area.

22. Determine hydraulic load on chosen surface ($\frac{m}{d}$):

hydraulic load on chosen surface $\left(\frac{m}{d}\right) = \frac{\text{daily flow}\left(\frac{\mathrm{m}^3}{d}\right)}{\text{actual surface area } (\mathrm{m}^3)}$

23. Determine organic load on chosen surface

$$Organic\ load_{chosen\ surface}\left(\frac{g\ BOD}{m^2}\right) = hydrolic\_load(\frac{m}{d}) \times BOD_{in}(\frac{mg}{l})$$