OPTIMIZING ACTIVATED SLUDGE SYSTEMS

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(1) Estimating reactor TSS concentration

(2) Estimating AS system capacity

(1) ESTIMATING REACTOR TSS CONCENTRATION

- This is done via a reactor volume (V) and secondary settling tank area (A_{ST}) cost optimization.

VOLUME OF REACTOR

- From steady state AS model, for anoxic-aerobic systems, mass of sludge in reactor is a function of organic load, WW chars and sludge age (SRT) –

$$MX_t = FS_{tiReactor}\,[A]$$

$$X_t V_p = Q_{i,ADWF} S_{tiReactor}\,[A]$$

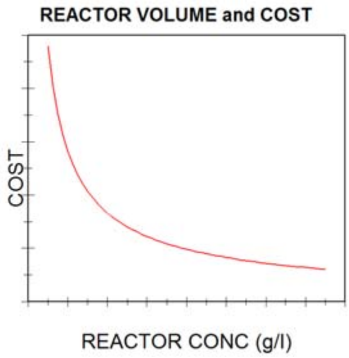
$$Q_{i,ADWF} = \frac{X_t V_p}{[A]\,S_{tiReactor}} \qquad \text{Eq 1}$$

where

$$[A] = (1 - f_{S'up} - f_{S'us})\frac{Y_H R_s}{(1 + b_{HT} R_s)}(1 + f_H b_{HT} R_s + f_{iOHO}) + \left[\frac{f_{S'up}}{f_{cv}} + \frac{X_{IOi}}{S_{ti}}\right] R_s$$

COST OF REACTOR

- So as reactor volume (V) decreases with increase in reactor conc X_t, reactor cost decreases.



Cost Reac = F_{Reac} (V_p)^P_{Reac}

AREA OF SETTLING TANK

- From 1D idealized flux theory, maximum overflow rate (q_{Amax}) = settling velocity of feed conc (V_S of X_t) reduced by a flux rating (F_j) to account for non-idealities.

$q_{i,pwwf}$ = V_S at X_t (m/h)
= V_0 exp(-n X_t) (m/h)

where

$q_{i,pwwf}$ =overflow rate at PWWF
= $Q_{i,pwwf}$ /A_{ST}
= f_q $Q_{i,adwf}$ / A_{ST} Eq 2

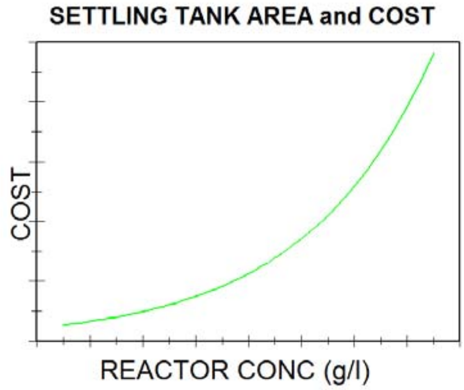
$$A_{ST} = \frac{1000 f_q Q_{i,adwf}/24}{0.8\, V_0 \exp(-nX_t)}$$

where
0.8 = Flux rating

Cost SST = F_{SST} (A_{ST})^P_{SST}

COST OF SETTLING TANK

- So as SST area (A_{ST}) increases with increase in reactor conc X_t, SST cost increases.



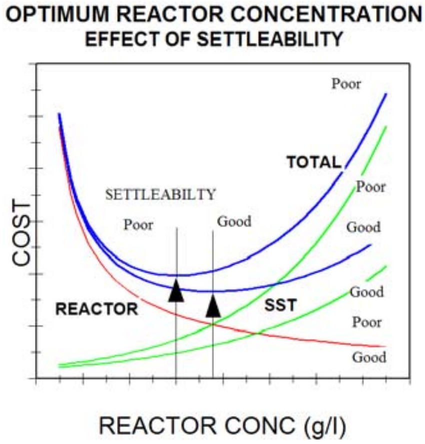
Cost SST = $F_{SST}\ (A_{ST})$^P_{SST}

COST OF AS-SST SYSTEM

- Total cost is the sum of the AS reactor and settling tank (SST) costs.
- Plot reactor, SST and total costs vs reactor concentration (X_t).
- At some X_t, total cost will be lowest.
- X_t from lowest cost depends on sludge age (R_s), WW strength (S_{ti}), raw or settled WW, PWWF/ADWF ratio (f_q), and local construction costs.

MINIMUM COST
EFFECT of SETTLEABITY

- As sludge settleability gets poorer, optimum reactor concentration decreases and total cost increases.



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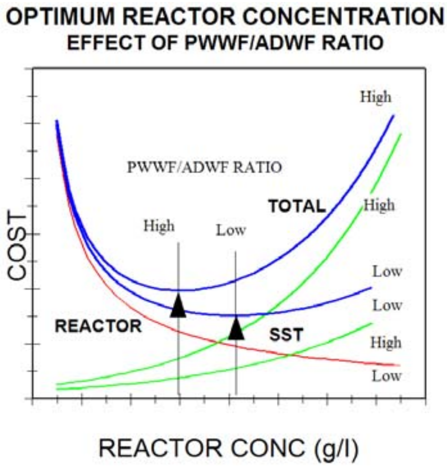
MINIMUM COST -
EFFECT of PEAK FLOW

- As peak flow factor (f_q) increases, optimum reactor concentration decreases and total cost increases.



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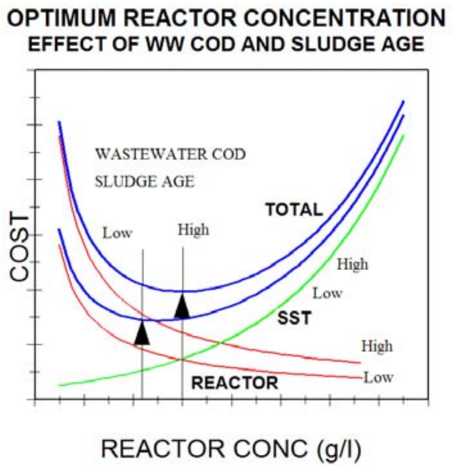
MINIMUM COST - EFFECT of SLUDGE AGE

- As sludge age and/or WW strength increases, optimum reactor concentration increases and total cost increases.



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CONCLUSION

- So the lower the WW strength (COD), the lower the sludge age, the poorer the sludge settleability and the higher the peak flow factor, the lower the optimum TSS concentration and the higher the total construction cost.
- This is one of the main reasons why AS systems in the US and Europe have lower reactor concentrations than in SA.

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BEPR - VOLUME OF REACTOR

- BEPR (BioP removal) systems produce more sludge (VSS, ISS and TSS) than N removal systems for the same organic load and SRT. So N&P removal systems have larger reactors than the equivalent N removal systems.
- Also, the balanced SRTs of N&P removal systems are longer than for N removal systems.
- BUT finding the reactor TSS conc is done the same way.

VOLUME OF REACTOR

- From steady state BEPR AS model, for anaerobic-anoxic-aerobic systems, mass of sludge in reactor is a function of organic load, WW chars, P removal and SRT –

VSS

$$\frac{MX_v}{MS_{ti}} = (1 - f_{S'us} - f_{S'up})[(1 - \frac{\%}{100} f_{Sb's}) \frac{Y_H R_s}{(1 + b_{HT} R_s)}(1 + f_{EH} b_{HT} R_s)$$

$$+ \frac{\%}{100} f_{Sb's} \frac{Y_G R_s}{(1 + b_{GT} R_s)}(1 + f_{EG} b_{GT} R_s)] + \frac{f_{S'up}}{f_{cv}} R_s \quad \text{kgVSS/(kgCOD load/d)} \quad (1)$$

ISS

$$\frac{MX_{Io}}{MS_{ti}} = (1 - f_{S'us} - f_{S'up})[(1 - \frac{\%}{100} f_{Sb's}) \frac{Y_H R_s}{(1 + b_{HT} R_s)}(f_{iOHO})$$

$$+ \frac{\%}{100} f_{Sb's} \frac{Y_G R_s}{(1 + b_{GT} R_s)}\{3.286(f_{XBGP} - f_{XBGPBM}) + f_{iPAOBM}\}] + \frac{X_{Ioi}}{S_{ti}} R_s \quad \text{kgISS/(kgCOD load/d)} \quad (2)$$

VOLUME OF REACTOR

$$\frac{MX_t}{MS_{ti}} = \frac{MX_v}{MS_{ti}} + \frac{MX_{io}}{MS_{ti}} = A = (1 - f_{S'us} - f_{S'up})[(1 - \frac{\%}{100} f_{Sb's}) \frac{Y_H R_s}{(1 + b_{HT} R_s)}(1 + f_{EH} b_{HT} R_s + f_{iOHO})$$

TSS

$$+ \frac{\%}{100} f_{Sb's} \frac{Y_G R_s}{(1 + b_{GT} R_s)}(1 + f_{EG} b_{GT} R_s + 3.286(f_{XBGP} - f_{XBGPBM}) + f_{iPAOBM})] + [\frac{f_{S'up}}{f_{cv}} + \frac{X_{Ioi}}{S_{ti}}] R_s$$

kgTSS/(kgCOD load/d) (3)

$$f_i = \frac{MX_v}{MX_t}$$

kgVSS/kgTSS (4)

- Where % is % of influent RBO obtained by PAOs (VFA+FBSO) and f_{XBGP} = total PAO P content, f_{XBGPBM} = P content of PAO biomass = 0.025 (same as OHO) and f_{iPAOBM} = ISS content of PAO biomass = 0.15 (same as OHO).

COST OF REACTOR & SST

- Once MX_t (TSS mass) is known for the BEPR system, the rest of the calculation for the X_t at which total reactor and SST cost is minimum is the same as for N removal systems.

(2) ESTIMATING AS SYSTEM CAPACITY

- This uses the same AS system and SST equations but now finds the highest Average Dry Weather Flow (ADWF) for existing reactor volume (V) and secondary settling tank area (A_{ST}).

ESTIMATING CAPACITY (1)

- From Eq giving mass of sludge in reactor for N removal system...

$$MX_t = FS_{tiReactor}\ [A]$$

$$X_t V_p = Q_{i,ADWF} S_{tiReactor}\ [A]$$

$$Q_{i,ADWF} = \frac{X_t V_p}{[A]\ S_{tiReactor}} \qquad \text{Eq 1}$$

where

$$[A] = (1 - f_{S'up} - f_{S'us}) \frac{Y_H R_s}{(1 + b_{HT} R_s)} (1 + f_H b_{HT} R_s + f_{iOHO}) + \left[\frac{f_{S'up}}{f_{cv}} + \frac{X_{IOi}}{S_{ti}}\right] R_s$$

ESTIMATING CAPACITY (2)

- From Eq giving mass of sludge (TSS) in reactor for N&P removal system...

$$\frac{MX_t}{MS_{ti}} = \frac{MX_v}{MS_{ti}} + \frac{MX_{Io}}{MS_{ti}} = A = (1 - f_{S'us} - f_{S'up})[(1 - \frac{\%}{100} f_{Sb's}) \frac{Y_H R_s}{(1 + b_{HT} R_s)} (1 + f_{EH} b_{HT} R_s + f_{iOHO})$$

$$+ \frac{\%}{100} f_{Sb's} \frac{Y_G R_s}{(1 + b_{GT} R_s)} (1 + f_{EG} b_{GT} R_s + 3.286(f_{XBGP} - f_{XBGPBM}) + f_{iPAOBM})] + [\frac{f_{S'up}}{f_{cv}} + \frac{X_{Ioi}}{S_{ti}}] R_s$$

Eq 1

kgTSS/(kgCOD load/d) (3)

$$f_i = \frac{MX_v}{MX_t}$$

kgVSS/kgTSS (4)

- So N&P removal AS has higher A value and longer balanced SRT than N removal plants.

ESTIMATING CAPACITY (3)

- From Eq 2 giving max overflow rate……
  - Setting Eq 3 equal to Eq 4, we get Eq 5.
  - Solve for X_t

$$V_s = V_0.\exp(-nX_t) \geq \frac{f_q Q_{i,ADWF}}{0.8 \ A_{SST}}$$

$$Q_{i,ADWF} = B.\exp(-nX_t)$$

where

$$B = 0.8 A_{SST} V_0 24/(1000 f_q)$$ Eq 3

$$Q_{i,ADWF} \frac{X_t V_p}{S_{tiReactor} A} = B.\exp(-nX_t)$$ Eq 4

from which

$$X_t = C.\exp(-nX_t)$$ Eq 5

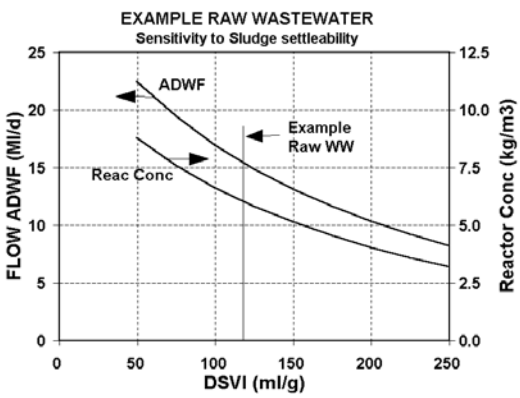
where

$$C = A.B.S_{tiReactor}/V_p$$

ESTIMATING CAPACITY (4)

- To obtain Q_{ADWF}, find X_t in Eq 5 by iteration for known values of WW characteristics ($f_{S'us}$, $f_{S'up}$, T°C and peak factor f_q), activated sludge characteristics (VSS/TSS f_i, V_0, n or SSVI or DSVI) and system sizing parameters (R_s, V_p, A_{ST} and flux rating).
- With X_t known, Q_{ADWF} from Eq 3 or 4.

EX - CAPACITY vs DSVI



- ADWF capacity (Ml/d) and reactor conc (X_t) with DSVI for V=11400m^3 and A_{ST}=2400m^2.

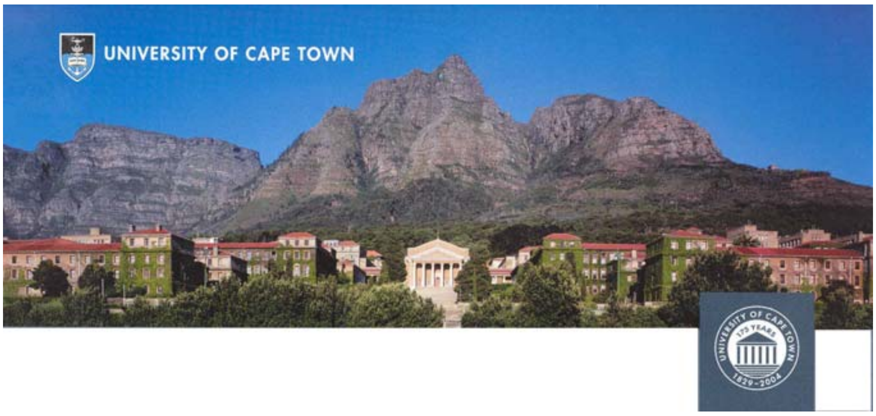
CLOSURE (1)

- The……
  - Longer the sludge age
  - Poorer the sludge settleability
  - Higher the influent COD concentration
  - Higher the unbiodegradable particulate COD fraction ($f_{S'up}$)……
- The lower the X_t and WWTP capacity.

CLOSURE (2)

- Sludge settleability is the most significant variable because we have the least control over it and has greatest impact on WWTP capacity
- Can use model for sensitivity analysis of WWTP capacity to sludge age and sludge settleability.
- Aeration capacity can also limit WWTP capacity – use AS model to check.

ACKNOWLEDGEMENTS



End of AS-SST Optimization. Continues with CFD modelling of SSTs