Activated Sludge - 3 Things You Need to Know to Improve Process Control

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Safety Moment

The 4 Principles of Hand Awareness

- **Wash your hands when they are dirty and before eating.**
- **DO NOT cough into your hands.**
- **DO NOT sneeze into your hands.**
- **Above all, DO NOT put your fingers into your eyes, nose, or mouth.**

Reduce transmission of flu, RSV, COVID, colds

Think • Plan • Act
Zero Injuries Today

When we continue to
Think • Plan • Act
we will achieve
Zero Injuries Today

Agenda

- Wastewater
- Activated Sludge Process
- Sludge Recirculation (RAS and Final Clarifiers Process Control)
- Sludge Wasting (SRT/MCRT Process Control)
- Aeration (Blowers/Aerators Process Control)

Wastewater

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Wastewater Chemistry

- Carbon
  - 2 Types – Organic carbon, Inorganic carbon (CO_2)
  - Organic C measured as carbonaceous Biochemical Oxygen Demand (cBOD) or Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC)
- Nitrogen – measured as TKN = Organic N + Ammonia-N
- Phosphorus – measured as TP = Dissolved P (ortho-P) + Particulate P
- Minerals – Ca, Mg, etc.
- Temperature
- pH
- Alkalinity
- Toxicity

Wastewater Biology

Bacteria – The stuff that you need to stain to see

- Heterotrophs – BOD bugs
- Autotrophs - Nitrifiers

Protozoa – The stuff that is easy to see in microscope

- Ciliates
- Amoeba
- Rotifers

BOD bugs

- Require organic C for energy and cell synthesis
- Respires dissolved oxygen (DO) or combined oxygen (NO_3), or fermentation
- Very diverse, many types – phosphate accumulating organisms (PAO), denitrifiers, etc.
- Filamentous bacteria are a special type

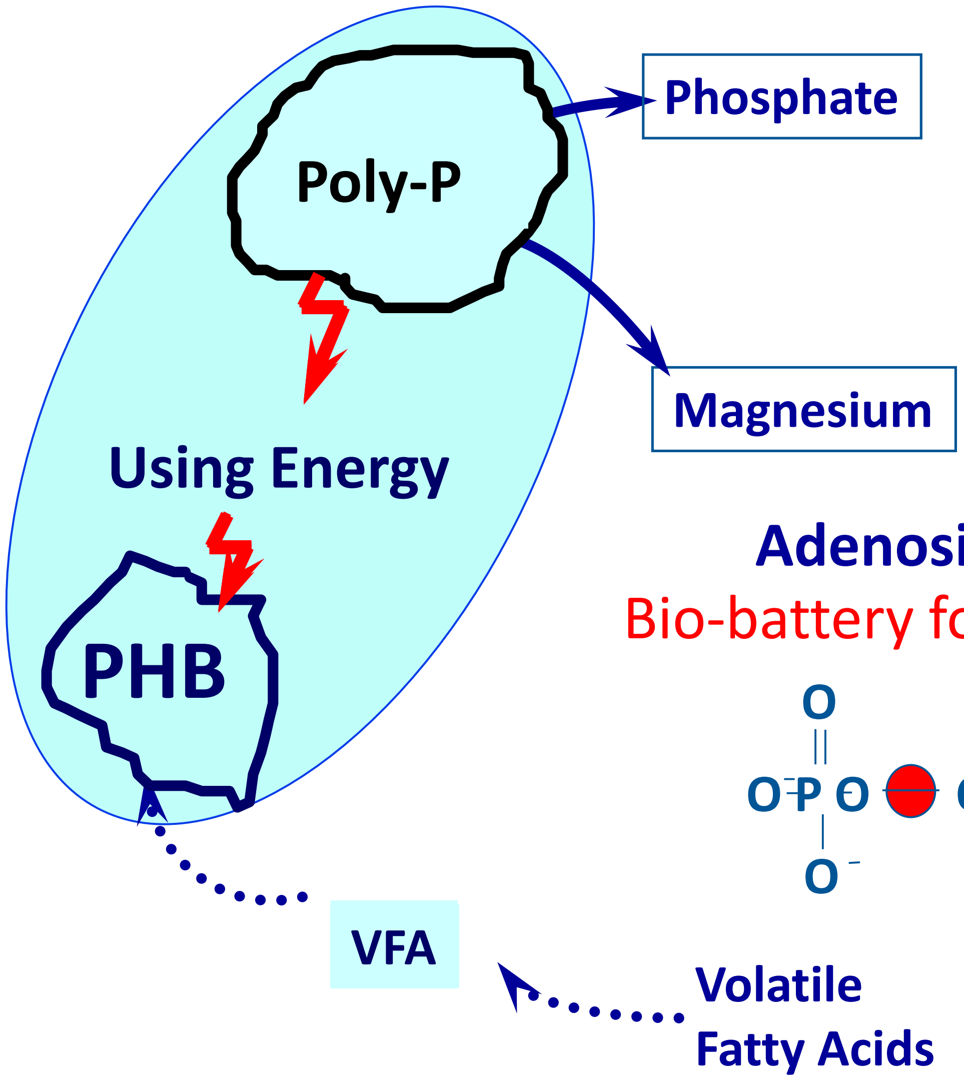
Wastewater Biology

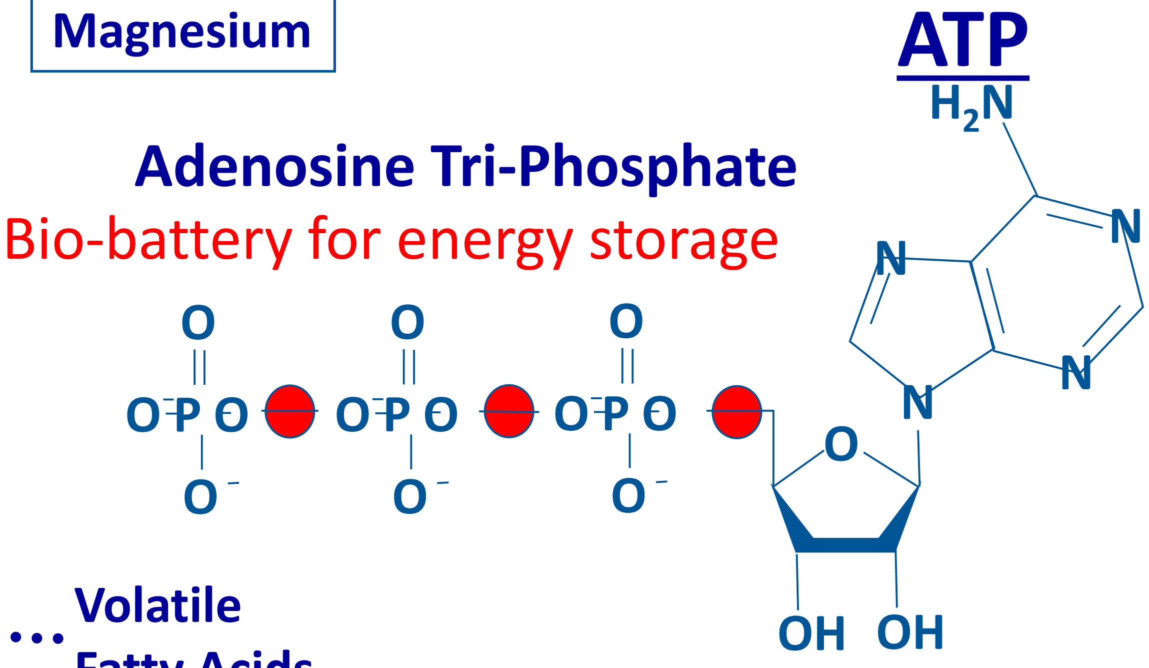
In biology, nothing is clear, everything is too complicated, everything is a mess, and just when you think you understand something, you peel off a layer and find deeper complications. Nature is anything but simple.

Richard Preston

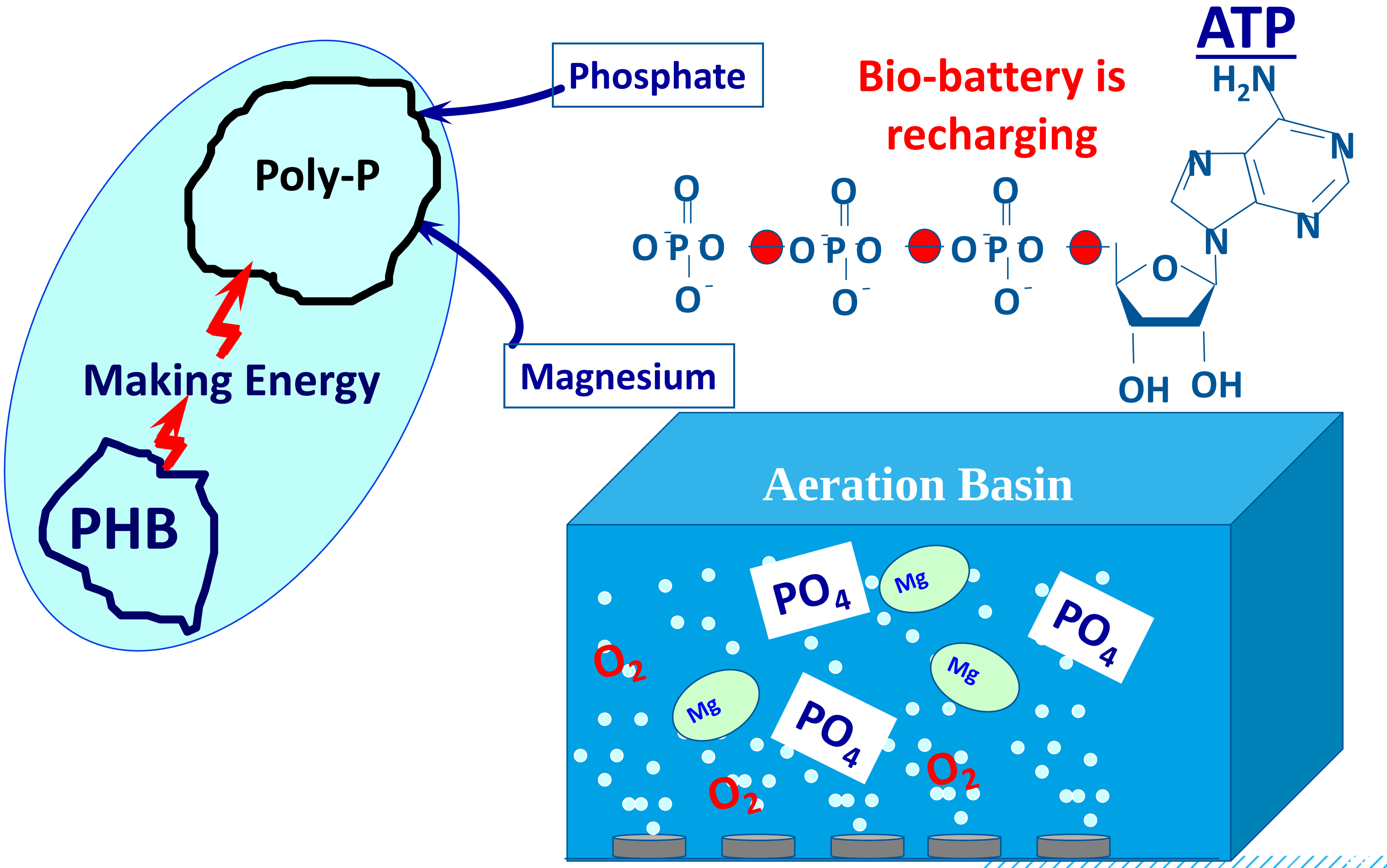
Author of The Hot Zone and The Demon in the Freezer

Phosphate Accumulating Organisms – Low/No DO Conditions





Phosphate Accumulating Organisms – with DO / Nitrate?



Nitrifiers

Require ammonia, nitrite for energy

Require DO for respiration

Use inorganic C for cell synthesis – this is a slow process

Low diversity, very few types - *Nitrosomonas, Nitrobacter, Nitrospira*

The Activated Sludge Process (ASP)

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Mixed Liquor Suspended Solids (MLSS)

Groups of bacteria aggregated together is called a floc

A group of flocs suspended in a wastewater aeration tank is called Mixed Liquor Suspended Solids (MLSS)

MLSS

X = Suspended Solids

X_{MLSS} = MLSS (mg/L)

X_{RAS} = RAS SS (mg/L)

Flow

Q = Flow

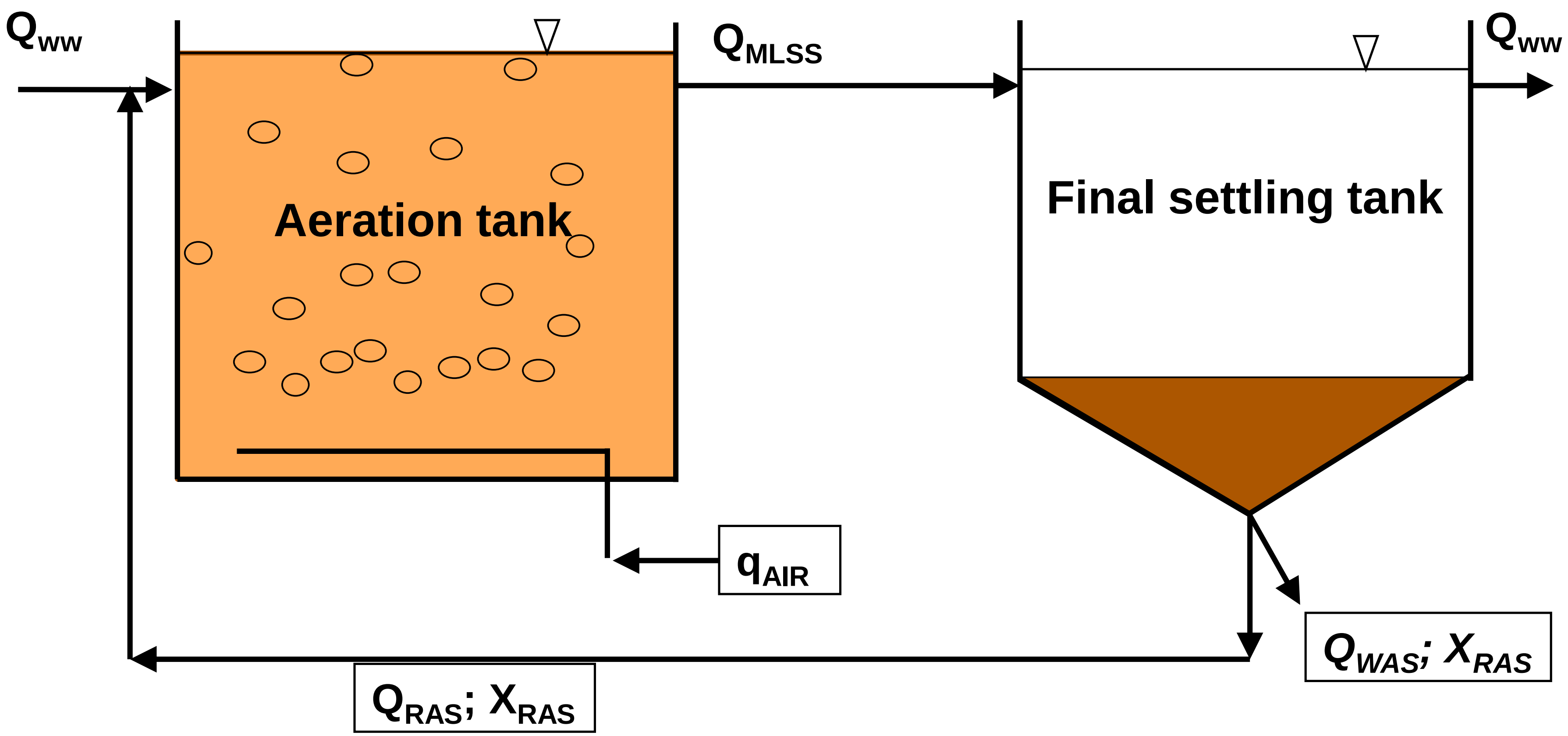
Q_{WW} = Wastewater Flow

Q_{RAS} = RAS Flow

$QMLSS = Q_{WW} + Q_{RAS}$

Q_{WAS} = WAS Flow

Activated Sludge Process



3 Handles for Activated Sludge Process Control

Aeration

- Aeration Tank Operation

Sludge Wasting

- Aeration Tank and Final Settling Tank Operation

Sludge Recirculation

- Final Settling Tank Operation

Sludge Recirculation

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The 2 Required Functions of a Settling Tank

Clarification – Solids Separation

Thickening – Transport & compaction

Key Performance Indicators – Setting Tank

- Effluent TSS
- Sludge Volume Index (SVI)
- Surface Overflow Rate (SOR)
- Solids Loading Rate (SLR)
- RAS Ratio Q_{RAS} / Q_{ww}

SVI

SVI is a measure of sludge settleability

SVI is the volume occupied by a unit mass of sludge

SVI = 30-min. settleometer volume (mL/L) / MLSS Concentration (mg/L) x 1,000

Good < 125; Fair 125 to 175; Poor >175

Surface Overflow Rate (SOR)

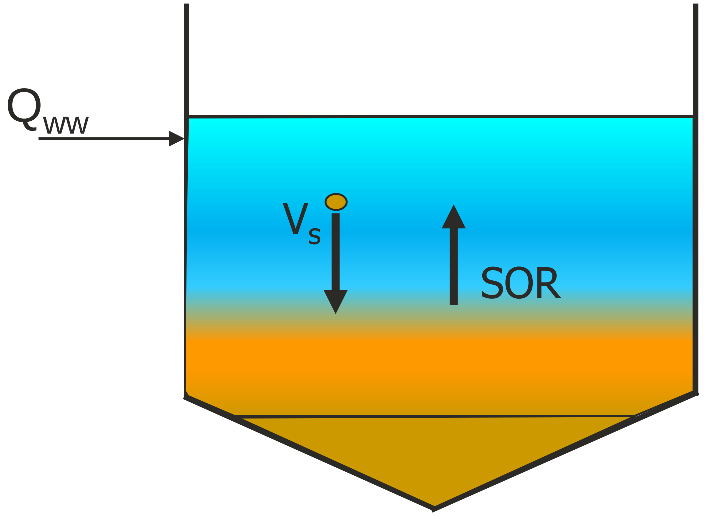
SOR = WW Flow (Q_{ww}) / Clarifier Surface Area (SA) = gal / day / ft^2 or m^3/m^2/day

But, looking at it a different way ->

(ft^3 / day) / ft^2 = ft / day -> velocity

So, SOR is the upward velocity of the water entering the clarifier

The allowable SOR depends on MLSS settling velocity – design standards typically 800 to 1,200 gpdsf (33 to 50 m^3/m^2/day) based on peak hourly flow



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Load

- Flow (or Volume) x Concentration = Load (mass)
- Mgal x mg/L * 8.34 = lbs.
- MGD x mg/L * 8.34 = lbs./day
- m^3 x mg/L / 1,000 = kg
- m^3/day x mg/L / 1,000 = kg / d

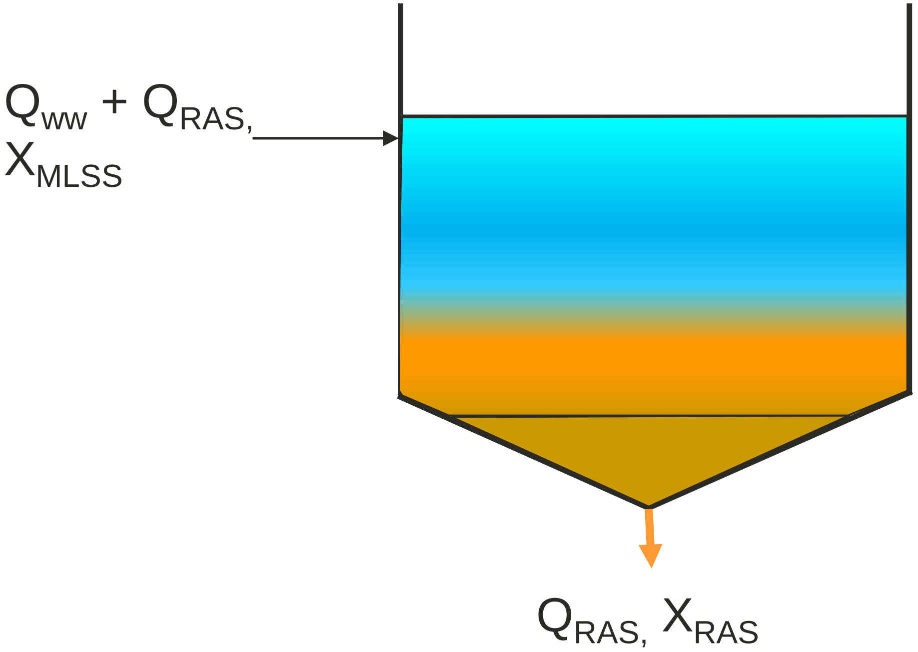
Solids Loading Rate (SLR)

SLR = MLSS Flow ($Q_{ww} + Q_{RAS}$) * MLSS Concentration (X_{MLSS}) / Clarifier Surface Area (SA)

SLR is reported as lbs./day/ft^2 or kg/d/m^2

SLR is the solids load applied to the clarifier

The allowable SLR depends on the compaction of the MLSS -> SVI – Design standards 35 to 50 ppdsf (170 to 240 kg/d/m^2)



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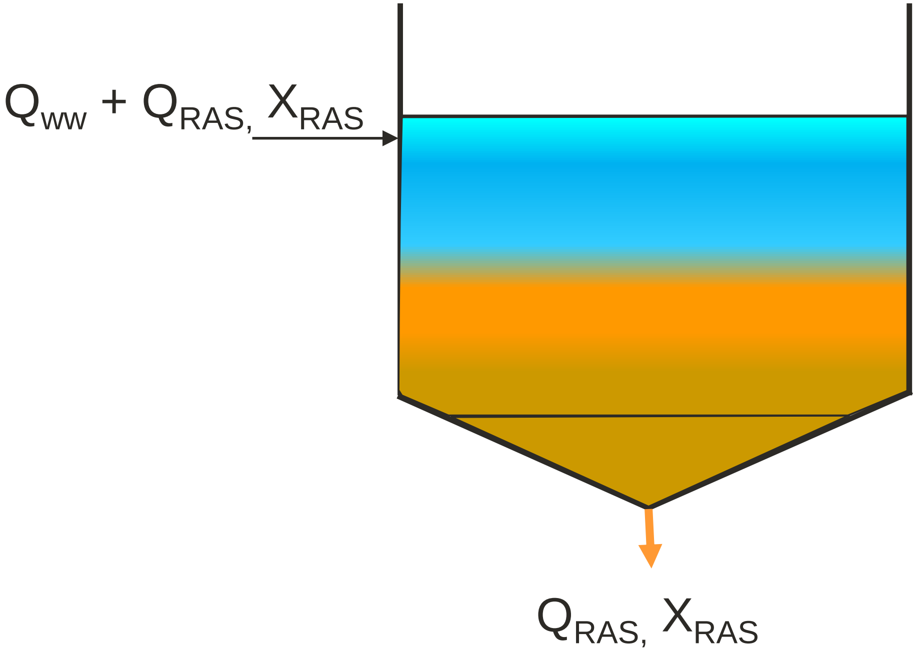
If SLR > Q_{RAS} * X_{RAS} ,sludge blanket rises



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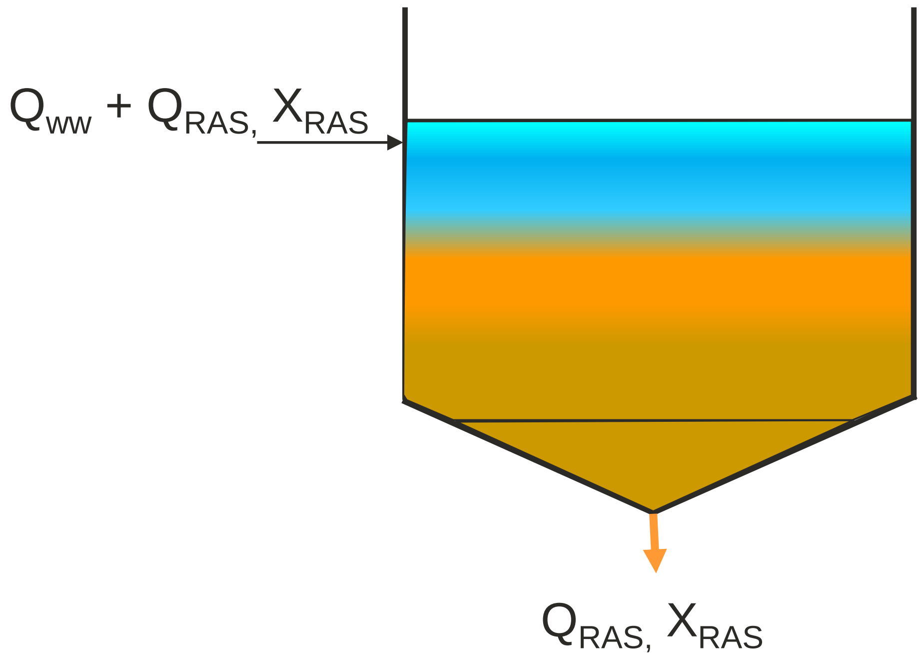

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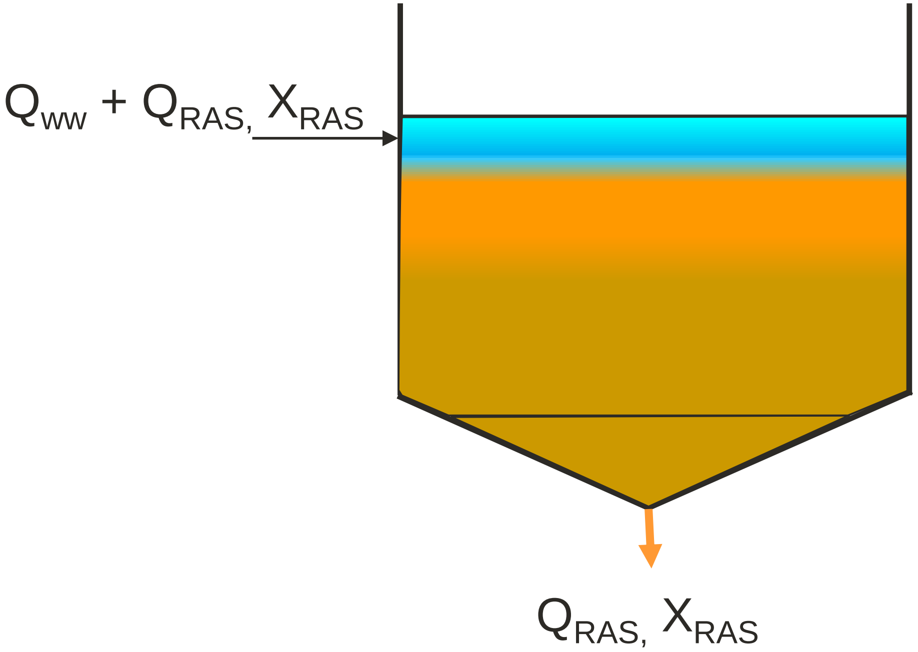

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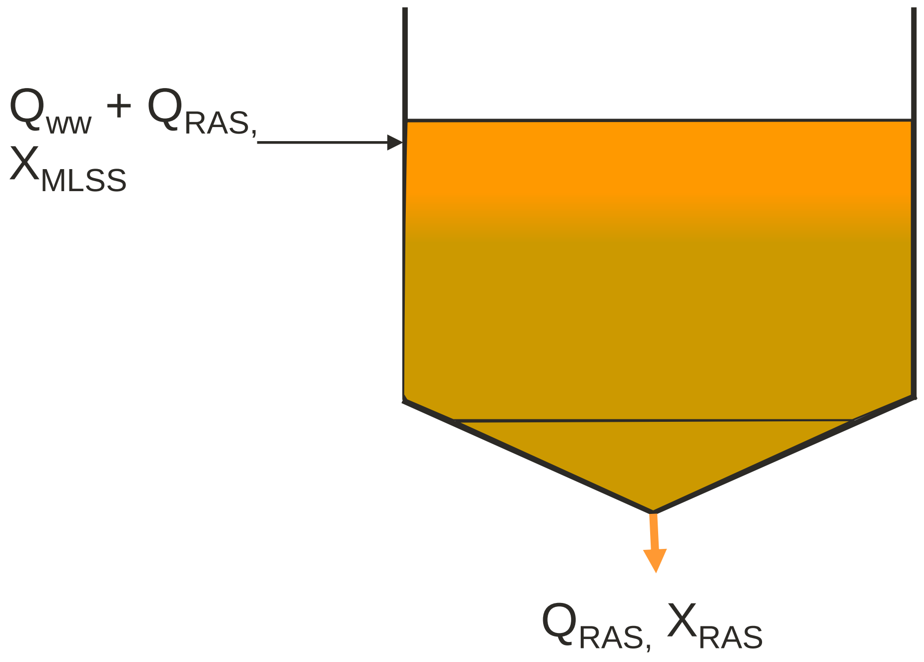

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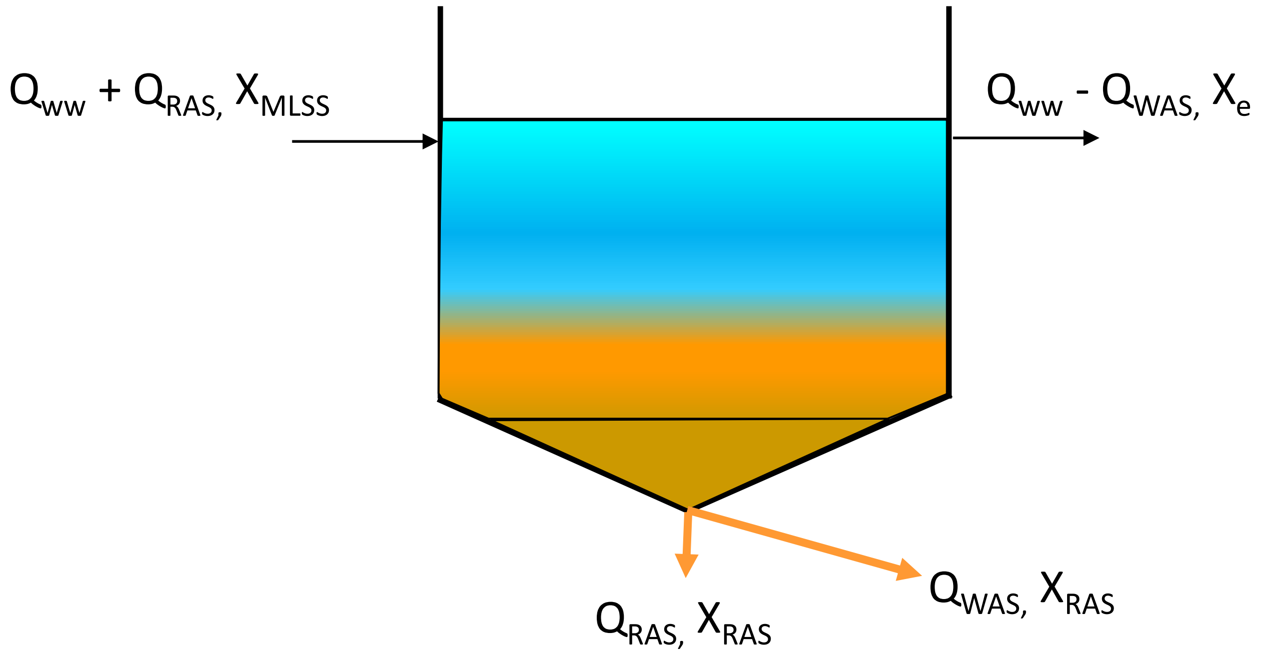
Sludge Blanket Variability is Normal

- Deep clarifiers (design) and maintaining shallow sludge blankets (operation), maximizes the available depth for the sludge blanket and increases clarifier reliability.

- Benefits of a shallow blanket:
- Keeps MLSS in the aeration tank
- Minimizes floating sludge due to denitrification
- Minimizes effluent phosphorus

$$(Q_{ww} + Q_{RAS}) \times X_{MLSS} = Q_{RAS} \times X_{RAS}$$

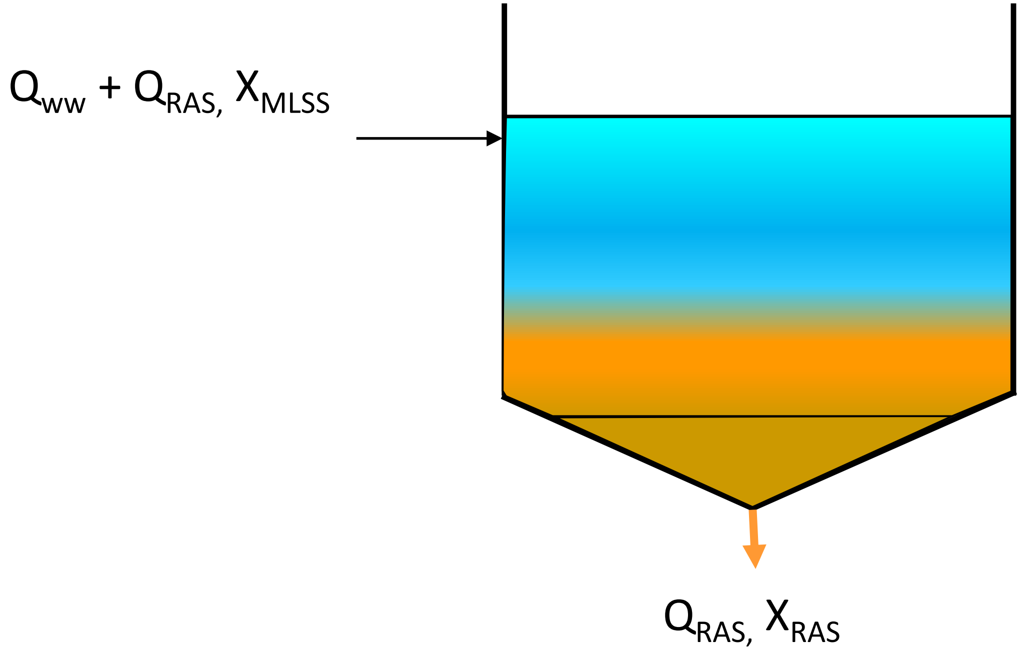


Degree of Thickening Achieved

$$\frac{X_{RAS}}{X_{MLSS}} = \left(\frac{Q_{ww} + Q_{RAS}}{Q_{RAS}}\right)$$

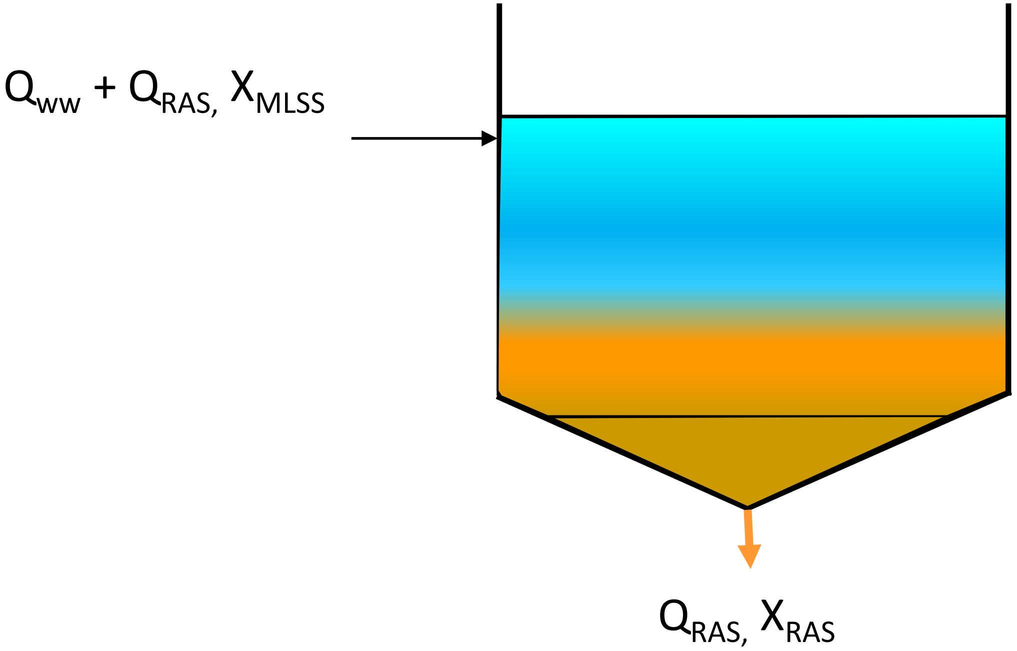
$$\frac{Q_{RAS}}{Q_{ww}} = Return\ Ratio\ (RR)$$

$$\frac{X_{RAS}}{X_{MLSS}} = \left(\frac{1 + RR}{RR}\right)$$



Degree of Thickening Achieved

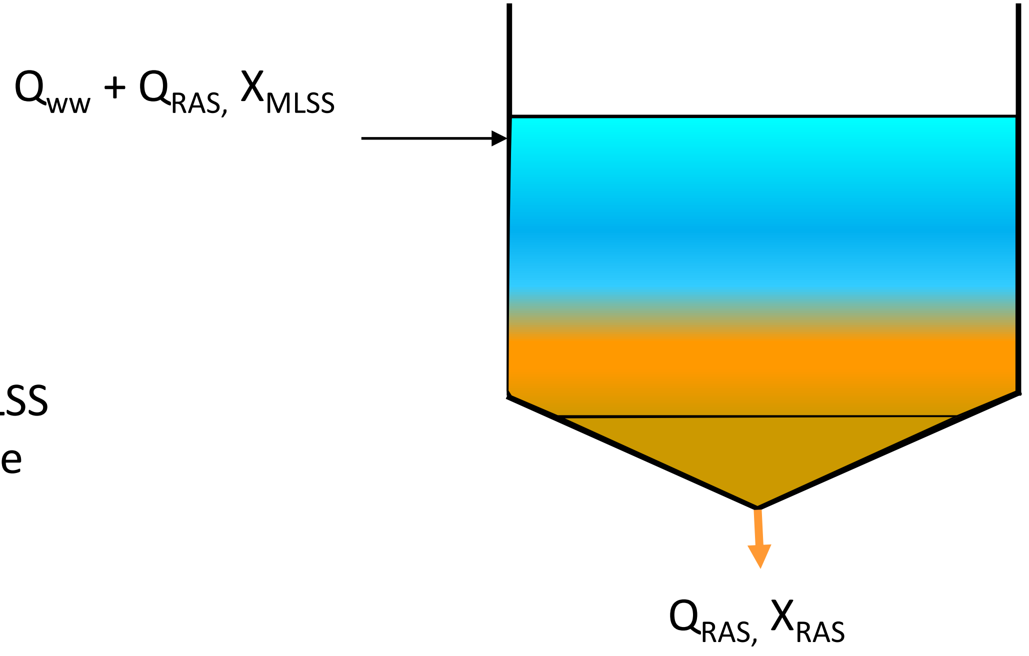
$RR = Q_{RAS} / Q_{WW}$	Thickening Factor, F
0.25	$X_{RAS} = 5 \times X_{MLSS}$
0.33	$X_{RAS} = 4 \times X_{MLSS}$
0.50	$X_{RAS} = 3 \times X_{MLSS}$
1.0	$X_{RAS} = 2 \times X_{MLSS}$
1.5	$X_{RAS} = 1.7 \times X_{MLSS}$



RAS Flow

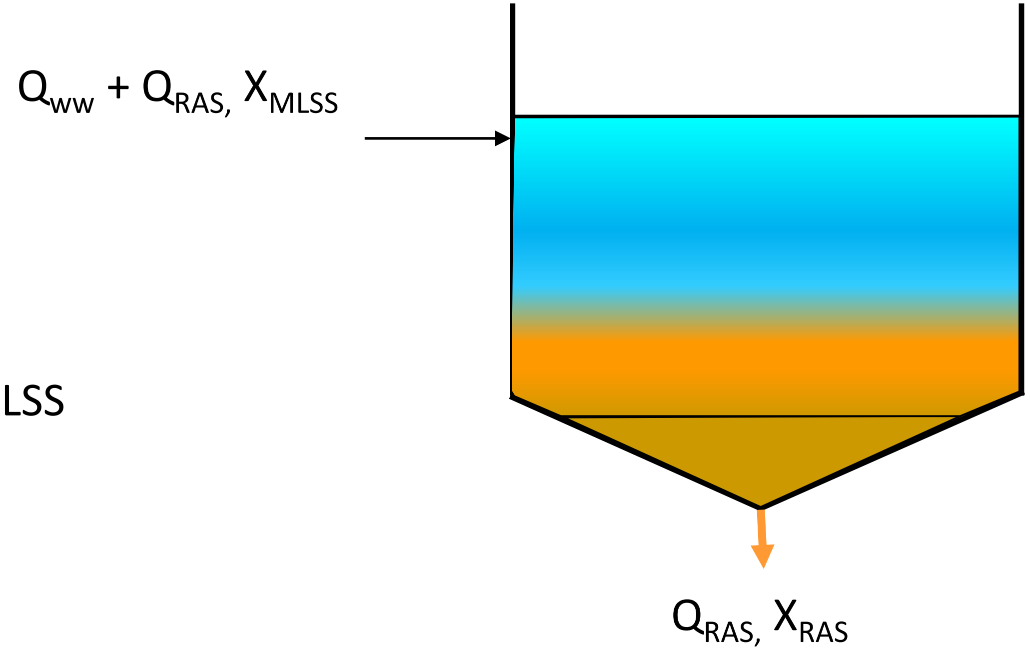
$$Q_{RAS} = \frac{Q_{ww} \times X_{MLSS}}{(X_{RAS} - X_{MLSS})}$$

The RAS flow rate required for a particular ww flow and MLSS concentration at a RAS SS concentration it is believed can be achieved.



Capacity

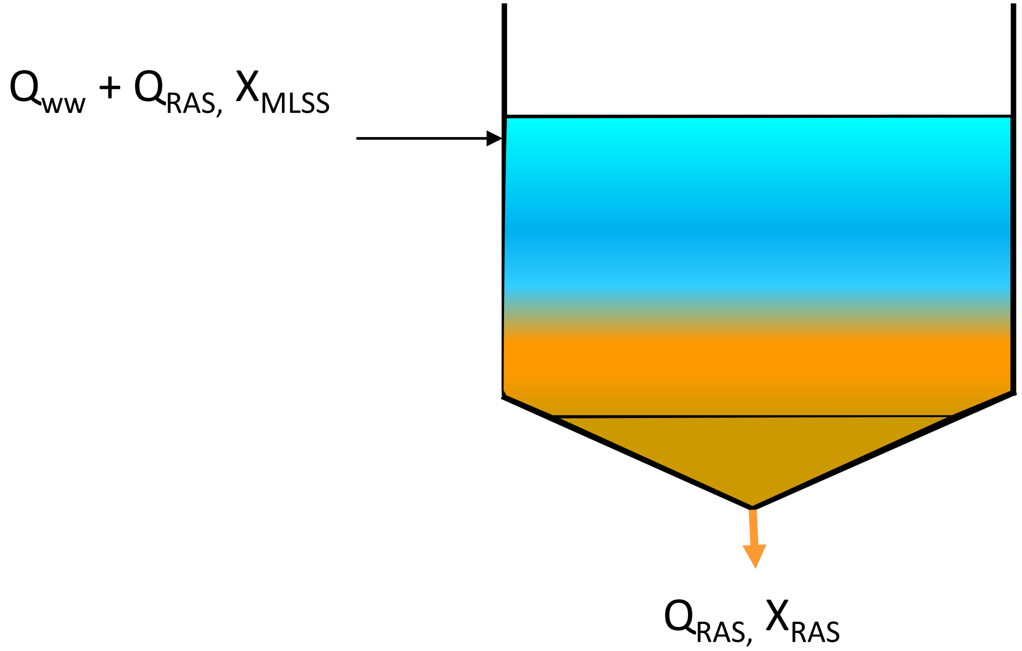
$$Q_{WW} = \frac{Q_{RAS} \times (X_{RAS} - X_{MLSS})}{X_{MLSS}}$$



The capacity of a clarifier for values of RAS flow rate and MLSS for a RAS SS concentration it is believed can be achieved.

Allowable Solids Loading Rate

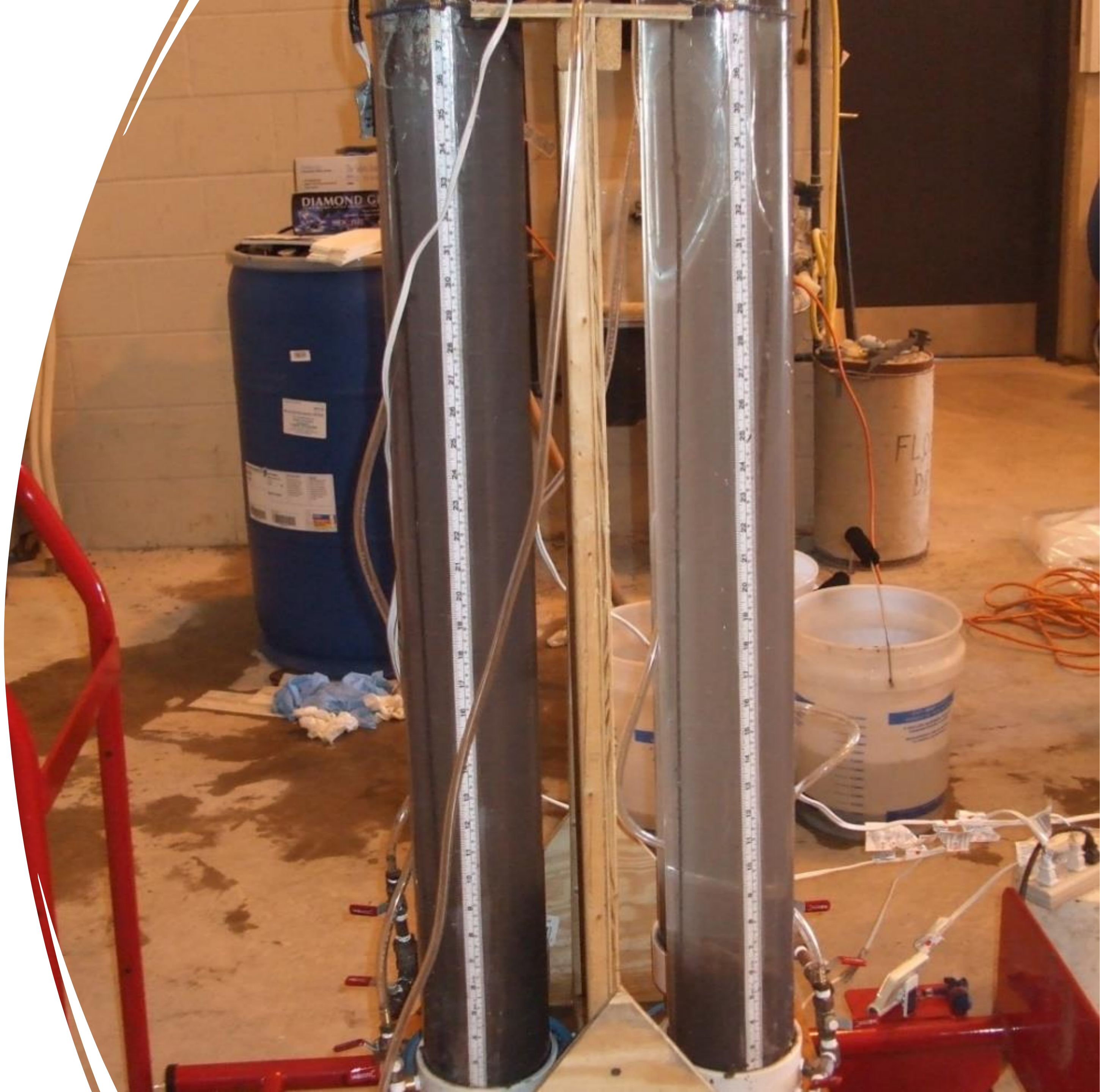
$$G_a = \frac{Q_{RAS} \times (Q_{WW} + Q_{RAS})}{A}$$



How to Determine G_a

- Direct Measurement
- Experimentally
- Correlations

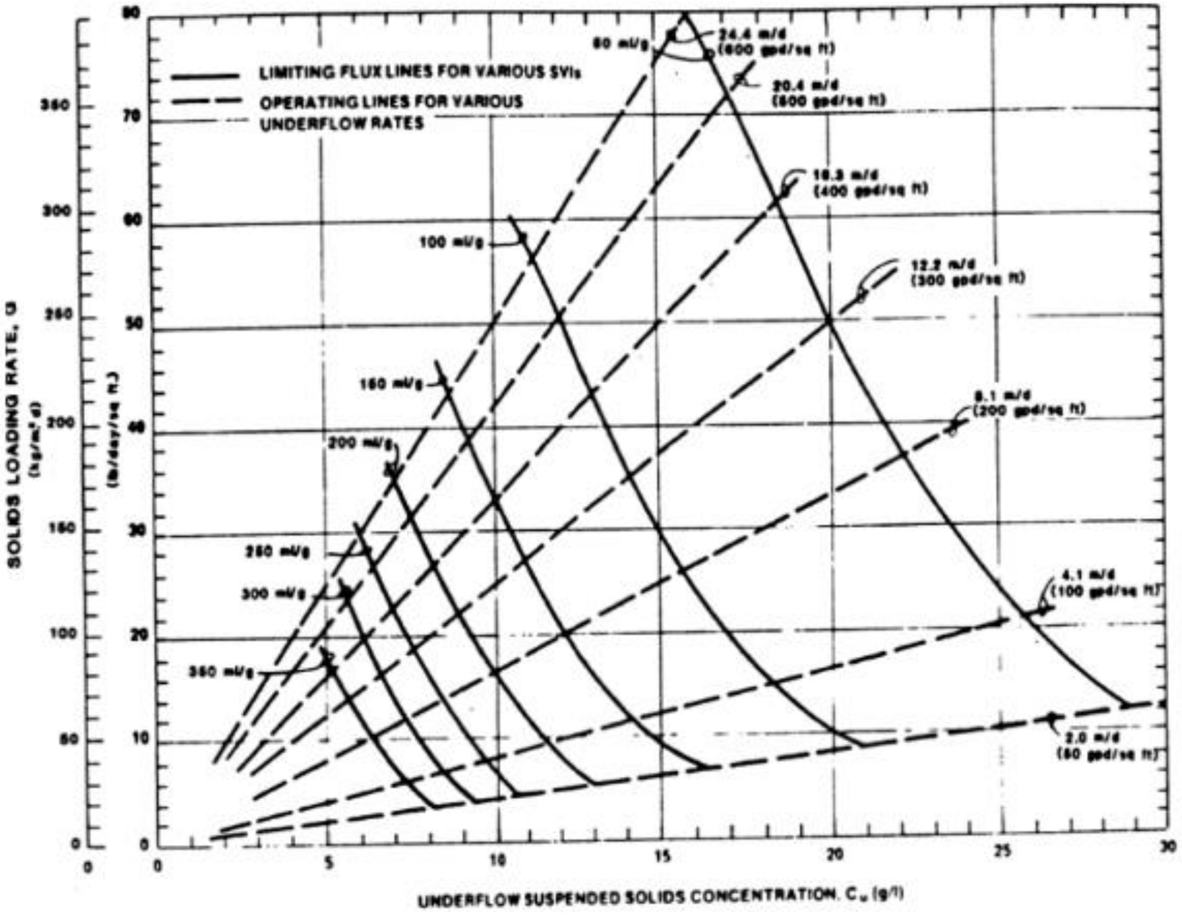
Experimental – State Point Analysis



Correlations with SVI

Clarifier operating conditions are determined with 2 of the following information:

1. SS loading rate (G)
2. Underflow rate (Q_{RAS}/A)
3. RAS SS, X_{RAS}



From Daigger and Roper, (1985), "The Relationship Between SVI and Activated Sludge Settling Characteristics", JWPCF, 57, p.859.

Sludge Wasting

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Sludge Wasting Purpose

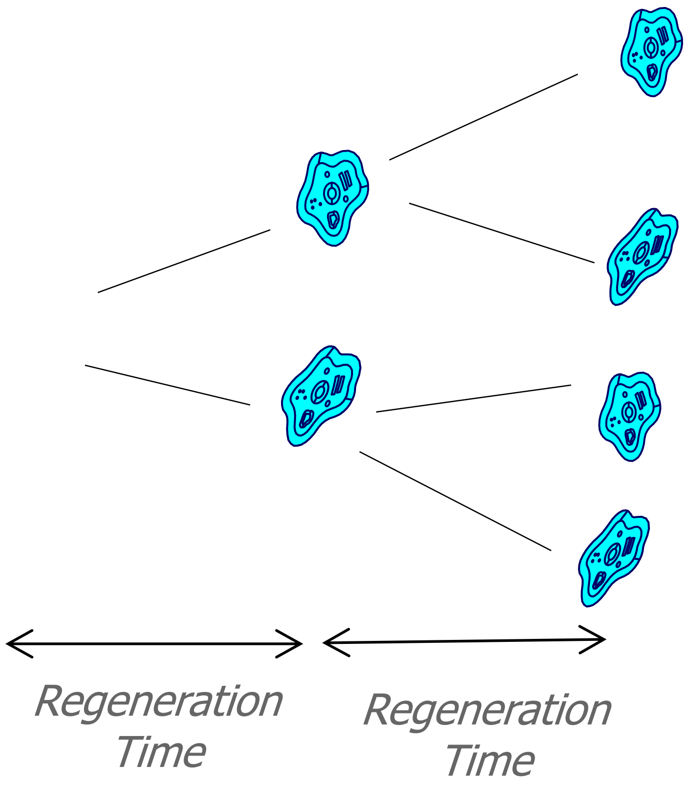
Meet target operating parameters

Achieve treatment goals

Key Performance Indicators – Sludge Wasting

- Solids Retention Time (SRT)
- Ammonia / Phosphorus Concentration
- Settleability / Sludge Quality
- Sludge Production

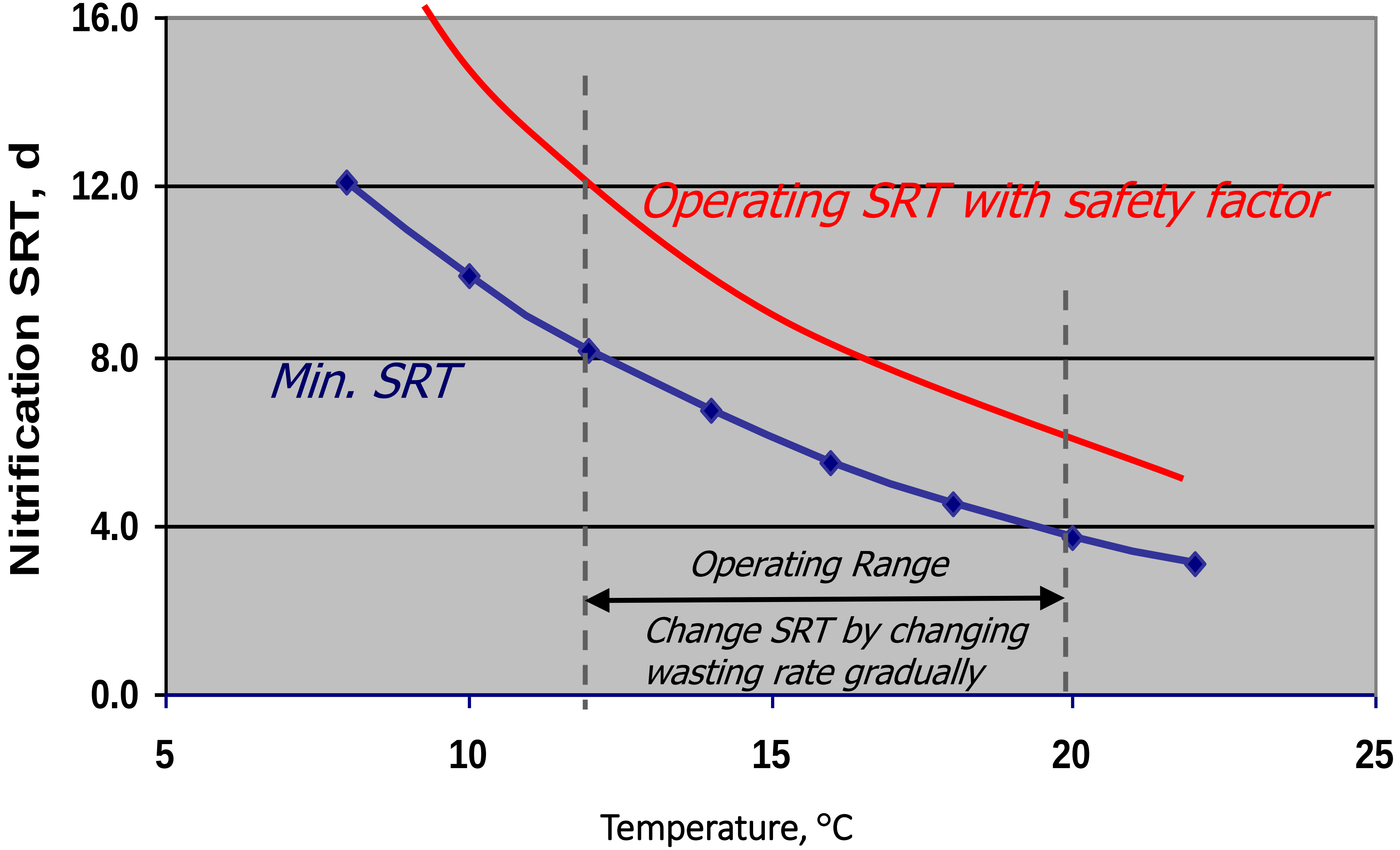
What is SRT?



- *Every organism has a regeneration time*
- *For organism to proliferate SRT>Regen Time*
- *Washout is when SRT< Regen Time*

- The length of time the bugs are held in the system
- SRT is 5 to 30 x hydraulic retention time (HRT)
- Related to the regeneration time of the organism of interest
- Target SRT depends on the type of bacterium that needs to be retained (and Temperature)

SRT required for nitrification



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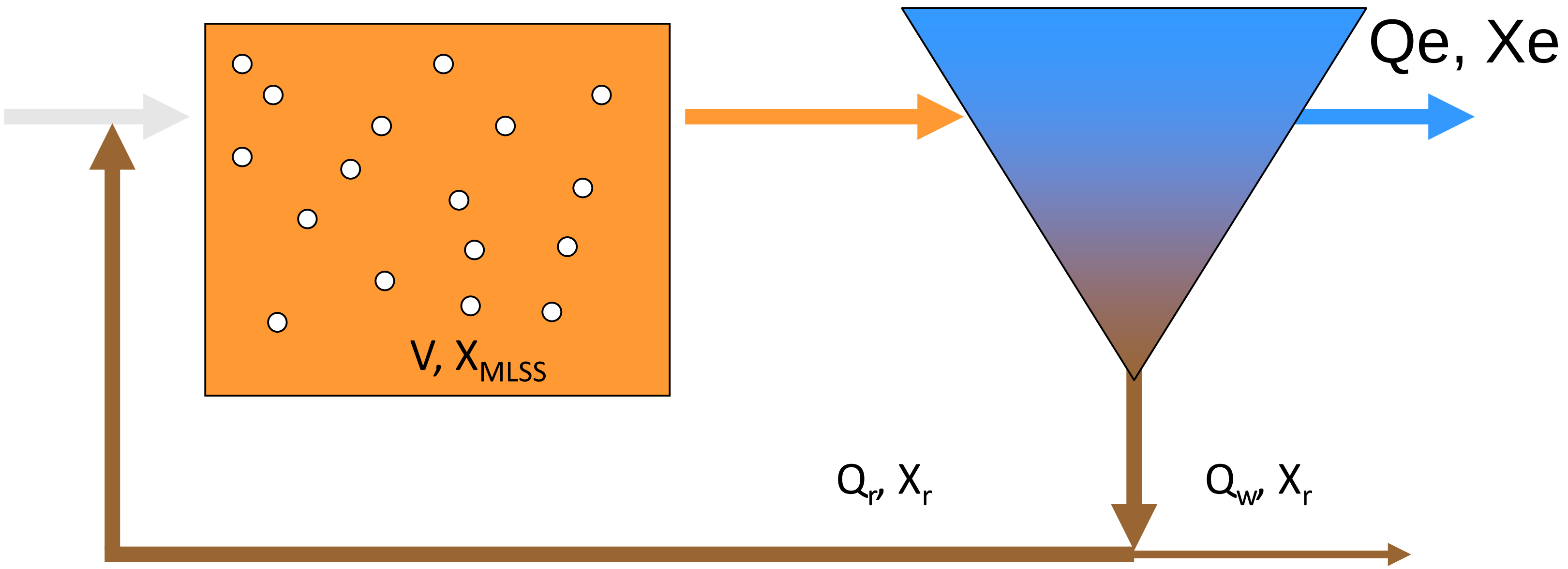
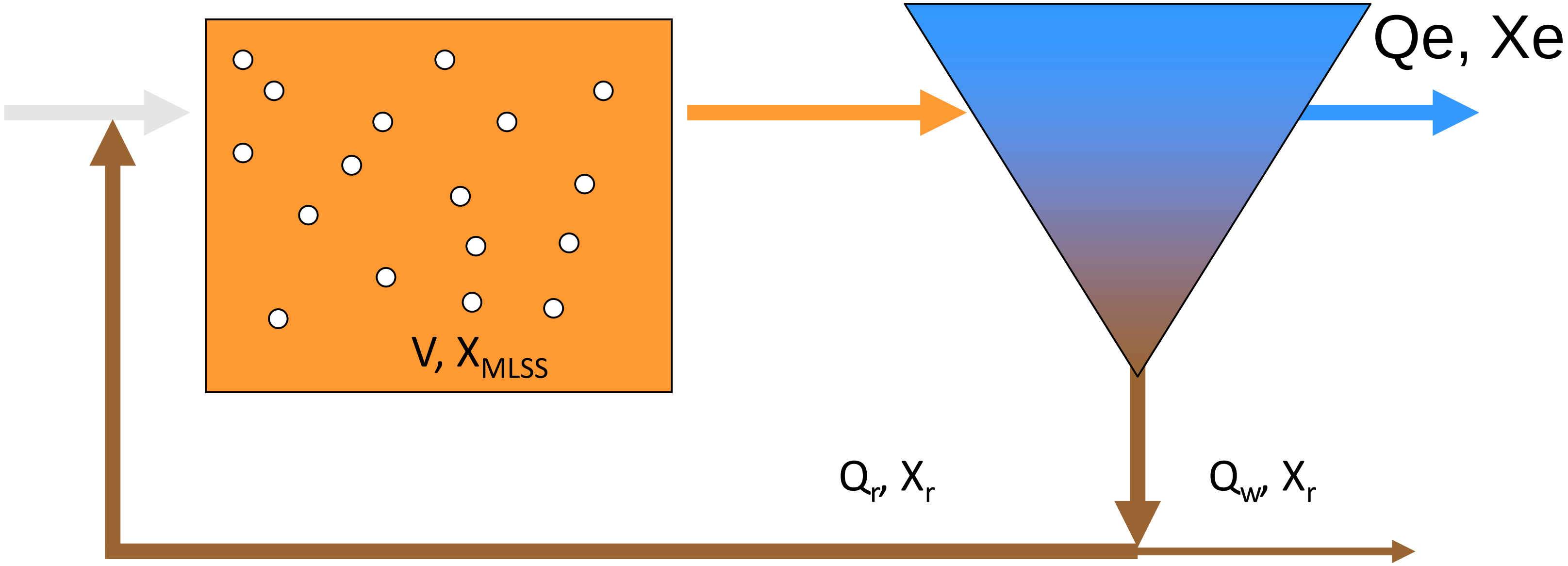


- *SRT = Mass of MLSS / Mass of Sludge Wasted*
- $SRT_{TOT} = \frac{X_{MLSS} \times V_{aeration\ tank}}{(Q_{WAS} \times X_{WAS} + Q_{ww} \times TSS_{eff})}$
- $SRT_{OX} = \frac{X_{MLSS} \times V_{oxic\ tank}}{(Q_{WAS} \times X_{WAS} + Q_{ww} \times TSS_{eff})}$
- $SRT_{AX} = \frac{X_{MLSS} \times V_{anoxic\ tank}}{(Q_{WAS} \times X_{WAS} + Q_{ww} \times TSS_{eff})}$
- SRT = MCRT = CRT



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- SRT = MCRT = CRT

SRT Cause & Effect

Function	SRT is low / too low	SRT is high / too high
MLSS	MLSS is lower	MLSS is higher
MLVSS (%)	MLVSS is higher	MLVSS is lower
Nitrification	Incomplete nitrification	-
Settleability	Fair to poor	Fair to poor
Sludge production	More sludge is produced	Less sludge is produced
Phosphorus removal	Lower in effluent	Higher in effluent
Energy Usage	Less energy is required	More energy is required
Clarifier SLR	Lower SLR	Higher SLR

Target SRT

- Conventional Plug Flow, Step Feed, Complete Mix – 3 to 15 days
- Extended Aeration – 20 to 40 days
- Oxidation Ditch – 15 to 30 days
- Sequencing Batch Reactor – 10 to 30 days

SRT Control

- Operate at minimum SRT required to achieve treatment goals
- Waste as frequently as practical; continuous, 1/hr, 1/shift, 1/day
- Adjust seasonally with temperature and treatment requirements
- Adjust gradually – no more than 10% at a time spread out over several days or weeks

Aeration

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Aeration Purpose

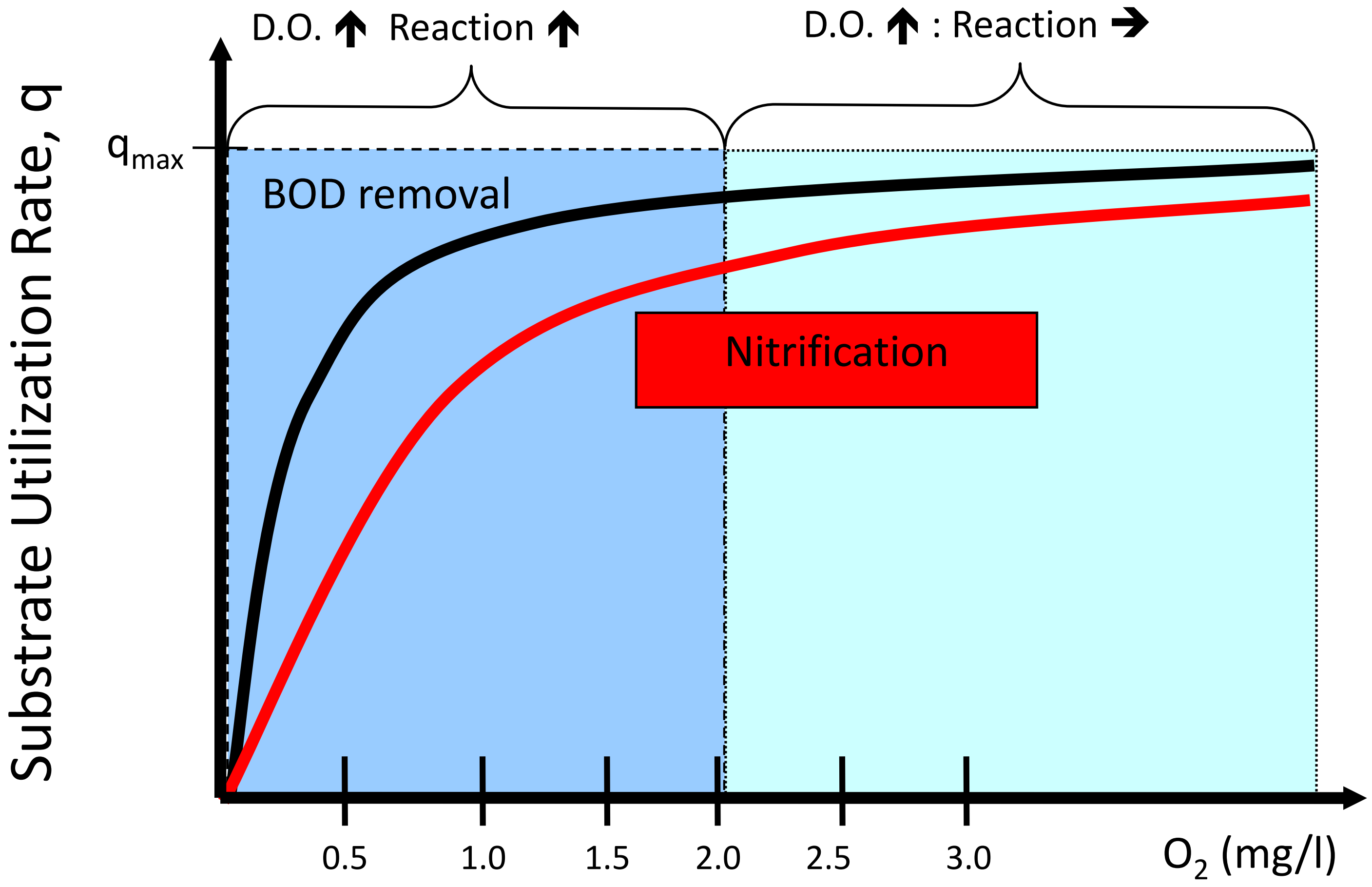
Creates the proper environment for growth of bacteria

Maintains bacteria in contact with the wastewater (food)

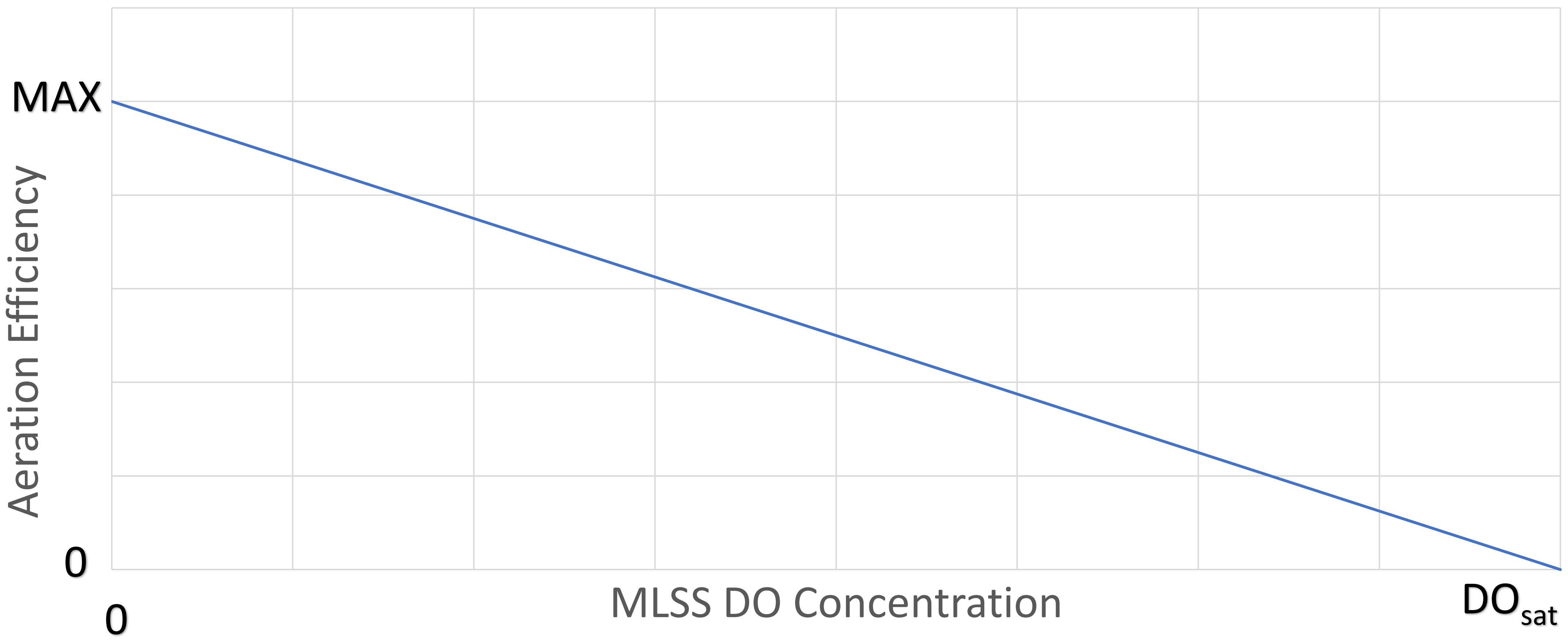
Key Performance Indicators - Aeration

- DO concentration
- Ammonia, Nitrate, Phosphate concentration
- Air Flow / Aerator hp
- Energy usage

DO and Reaction Rate



DO and Aeration Efficiency



Aeration Calculation

Actual Oxygen Requirement (AOR)

Standard Oxygen Requirement (SOR)

Air Flow / Aerator Horsepower

Actual Oxygen Requirement (AOR)

- BOD: + 1.0 to 1.5 lbs. O_2/lbs. BOD_{rem} depending on T and SRT
- Nitrification: + 4.6 lbs. O_2 / lbs. ammonia-N nitrified
- Denitrification - 2.3 lbs. O_2 / lbs. nitrate-N denitrified (credit)

Standard Oxygen Requirement (SOR)

Correction Factor for Environmental and Wastewater Characteristics = 0.3 to 0.6

SOR = AOR / Corr. Factor

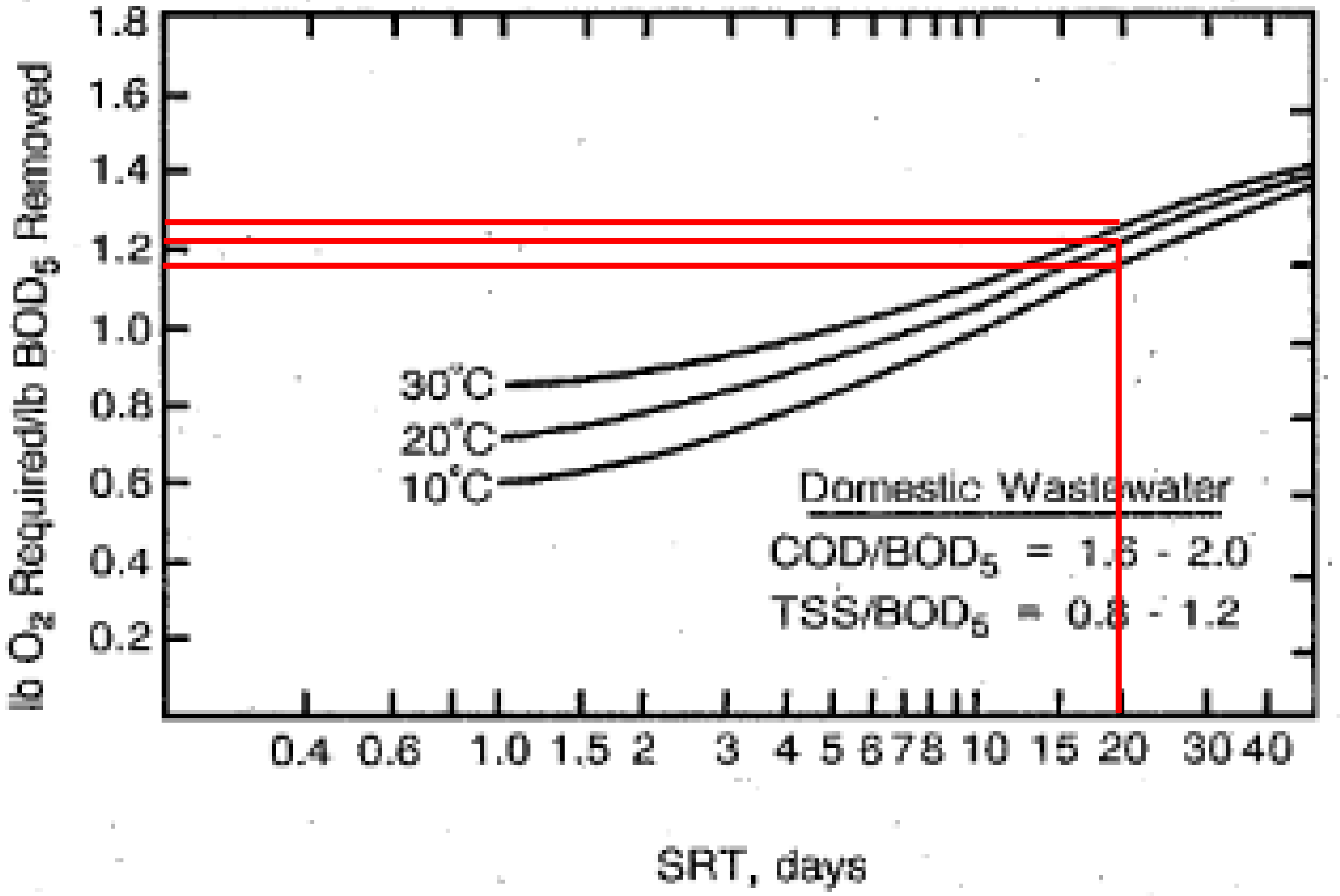
Oxygen Transfer Efficiency

Mechanical Aerators – 1 to 3 lbs. O_2/hp-hr

Diffused Air – 0.5% to 2.5% / ft. water depth

Example

- Q = 1 MGD
- WW $cBOD_5$ = 150 mg/L
- Eff = $cBOD_5$ = 10 mg/L
- WW NH_3-N = 40 mg/L
- Eff = NH_3-N = 1 mg/L
- SRT = 20 days
- Depth = 15 ft.
- No denitrification



AOR

1 MGD x (150– 10) mg $cBOD_5$/L x 8.34 x 1.2 lbs. O2/lbs. $cBOD_5$= 1,501 lbs. O_2 /day

1 MGD x (40 – 1) mg NH3-N/L x 8.34 x 4.6 = 1,535 lbs. O_2 /day

AOR = (1,501 + 1,535) lbs. O_2 /day = 3,036 lbs. O_2 /day = 127 lbs O_2/hr

Mechanical Aerators

SOR = 127 lbs. AOR /hr ÷ 0.55 = 231 lbs. O_2 /hr

231 lbs. O_2 /hr ÷ 3 lbs. O_2/hp-hr = 77 hp

T / DO	1.0	1.5	2.0	2.5
10	63	67	71	75
15	66	70	75	80
20	67	72	77	84
25	67	73	79	87

(77 hp – 67 hp) x 0.75 kW/hp x 24 x 365 = 65,700 kWh/yr potential savings

Diffused Air – Oxygen Demand

SOR = 127 lbs. AOR /hr ÷ 0.4 = 318 lbs. O_2 /hr

SOR = 318 lbs. O_2 /hr x 24hr./day = 7,632 lbs. O_2 /day

SOTE = 15 x 2% = 30%

Qair = 0.04 scfm/lbs. O_2/day x SOR / SOTE = 0.04 x 7,632 ÷ 0.3 = 1,018 scfm

WP = 1,018 scfm ÷ 25 scfm/hp = 40 hp

Diffused Air – Mixing

15 scfm / 1,000 ft^3 for fine bubble

For a 750,000 gal. tank (100,000 ft^3) -> 1,500 scfm

WP = 1,500 scfm ÷ 25 scfm/hp = 60 hp

Summary

- Final Clarifier Operation – RAS
- Sludge Wasting – SRT/MCRT
- Aeration

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