Better Plants
U.S. DEPARTMENT OF ENERGY

Webinar #2 for IAC Directors: Optimize the Activated Sludge Process, Save Energy, & Reduce Nutrient Discharge

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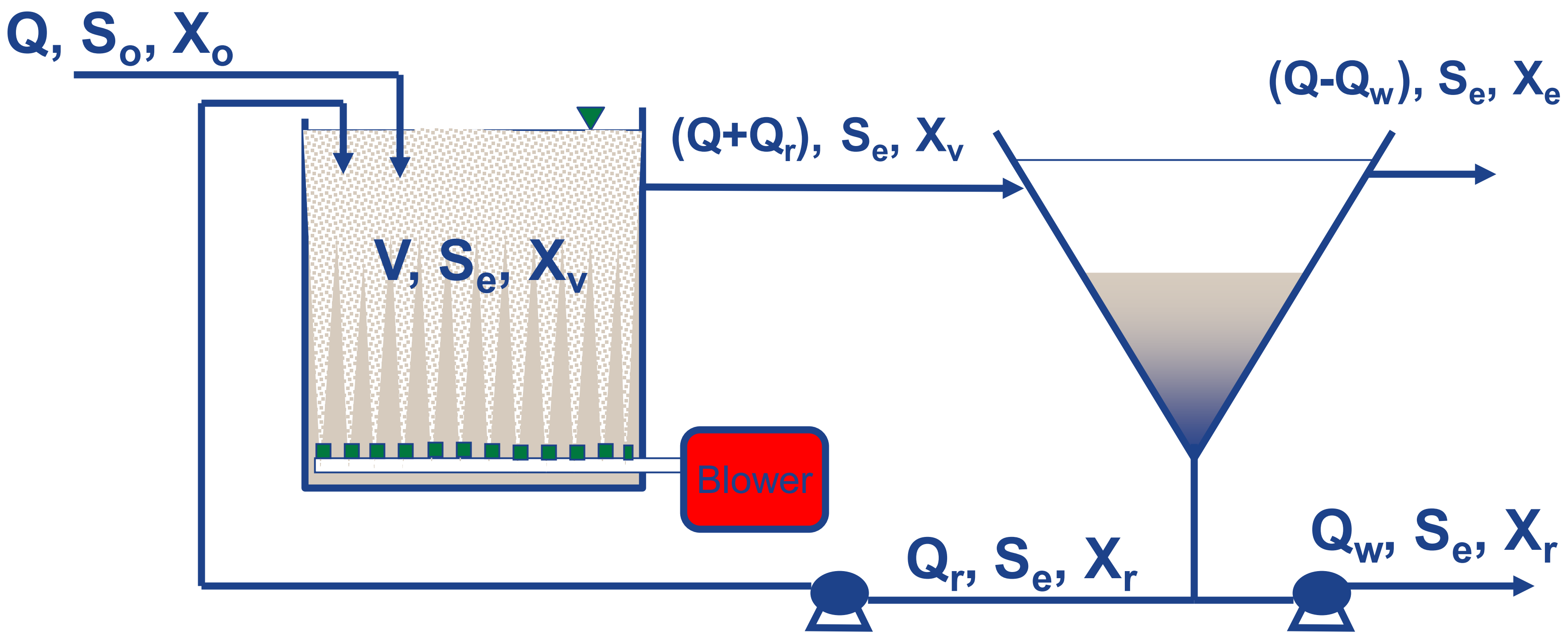
Optimize Your Wastewater Plant Operations; Save Energy – Save Money; Reduce Nutrient Discharge

Objectives of Biological Treatment

- Oxidize dissolved and particulate biodegradable constituents into acceptable end products
- Capture suspended and nonsettleable colloidal solids into a biological floc or biofilm
- Transform or remove nutrients such as N and P
- Remove specific trace organic compounds

Primary reference: Metcalf & Eddy 4th Edition

Activated Sludge: Basics of Design



Optimize the Activated Sludge Process by Controlling SRT

What is Sludge Age?

θ_c = MCRT = SRT = sludge age

It is how long in days (on average) the biomass stays in the activated sludge system until the biomass exits the system as waste activated sludge solids or as TSS in the effluent.

Optimize Your Process by Controlling SRT

SRT controls the following:

Sludge settleability
Effluent quality
MLSS concentration (biomass inventory)
Sludge production
Oxygen requirements
Nitrification efficiency

Therefore, it is imperative that the activated sludge process be operated at a SRT that provides excellent process performance and satisfies effluent quality requirements in a cost-effective manner!

Evaluation of Settleability

- Settleometer
  - Use settleometer … not graduated cylinder
  - Indicator of clarifier performance
  - How well the biomass settles, compacts, and clears
  - May give mixed signals
  - Part of the SVI test

Optimize the Activated Sludge Process by Efficiently Controlling the Aeration System

Aeration Devices

- Overall, aeration devices used for the activated sludge system represent the most significant consumers of energy within a WWTP.

- Most aeration systems are classified as:
  - Diffused
  - Dispersed
  - Mechanical (surface)

The ability of any type of equipment to dissolve oxygen within a wastewater treatment system depends on:

- **DO concentration**
- Diffuser device type
- Basin geometry
- Diffuser depth
- Turbulence
- Ambient air pressure
- Temperature
- TDS concentration
- Spacing and placement of the aeration devices
- Diurnal variations in wastewater flow and organic load

Having high DO (dissolved oxygen) concentrations within aeration tanks is a waste of energy!

- If the system uses blowers, an operator should cut back on blowers or blower output.
- If the facility has coarse bubble diffusers, then a fine-bubble-diffuser system that is more efficient and uses less energy should be considered.

Having high DO (dissolved oxygen) concentrations within aeration tanks is a waste of energy!

- If a facility has surface aerators, the submergence on the unit may be decreased, which results in:
  - Less DO concentration
  - Less amperage load on the motor (less electrical cost)
- If the liquid level of the basin cannot be adjusted, then:
  - VFDs should be installed on the aerators, or
  - Aerators should automatically start and stop based on time intervals or DO control system.

Automated DO Control

- A WWTP may save considerable energy by quickly adjusting to variable conditions within the basin
- Oxygen required for biotreatment is proportional to organic and ammonia loading in the influent wastewater.
- Oxygen demand for aeration drops in the middle of the night and peaks in the morning and evening.

Automated DO Control

- Tight DO control can save a WWTP between **10% and 30% of total energy costs.**
- Energy savings will be site specific and are highly dependent on the control system in place prior to the upgrade to automated process control.
- The payback period for installing automated DO control is typically a few years.

How Automatic DO Control Works

- These systems use real-time dissolved oxygen (DO) concentration readings from DO probes located within the aeration basins as inputs to a process controller.
- The process controller provides control output to the aeration system that responds by:
  - adjusting the surface aerator or blower speed
  - turning surface aerators off and on
  - adjusting the position of variable vane diffusers on the blower
  - adjusting the position of the drop-leg control valves to deliver the proper air amount

Types of DO Control Systems

- Simple control system that might use one DO probe and one target DO concentration for all aeration basins
- More complex control system involving individual DO probes and air header control valves for each basin and/or stages within each basin

Major Components of Automated DO Control System

- **DO Probes** – membrane, galvanic, or new optical technology
- **Blower Air Flow Control** – the total air flow supplied to the system is controlled by modulating the air flow rate delivered by the blowers
- **Basin Air Flow Control** – the total air flow supplied by the blowers is divided between multiple aeration tanks and multiple grids in each tank
- **Process Control System** – the aeration system process controllers receive info from the DO probes, process results, and send signals to air control mechanisms to make a change if needed

Blower Air Flow Control

- Positive displacement blowers can use VFDs to modulate air flow.
- Air flow for multi-stage centrifugal blowers is often controlled by inlet throttling; VFDs also can be used in some cases to improve efficiency and downturn.
- New single-stage centrifugal blowers use variable speed, inlet guide vanes and variable discharge diffusers to modulate flow for greater energy efficiency.

Process Control System

- Most systems are composed of programmable logic controllers (PLCs), usually networked together by a Supervisory Control and Data Acquisition System (SCADA).

Automated DO Control Systems

- They typically use some form of a feedback control loop, whereby blower and aeration basin air flow rates are manipulated in response to changes in the DO level in the aeration basin.
- Control strategies can be very simple, such as on-off or setpoint control, or complex approaches based on proprietary algorithms.

DO Measurement Equipment

- ***Membrane electrodes*** are composed of two metal electrodes separated from a test solution by a membrane. As oxygen permeates the membrane, the cathode reduces it and creates a potential that can be correlated to the amount of DO.
- They are fairly reliable but must be calibrated frequently.
- The membranes must also be replaced relatively frequently.

DO Measurement Equipment

- ***Galvanic electrodes*** apply a galvanic current to measure the oxygen.
- This type of probe has much less maintenance than membrane-style probes and can obtain slightly better energy savings as it maintains its accuracy longer.

DO Measurement Equipment

- ***Optical DO probes*** measure changes in light emitted by a luminescent or fluorescent chemical and relate the rates of change in the emission to the DO concentration in solution.
- They work on the principle that DO quenches both the intensity and duration of the luminescence or fluorescence associated with certain chemical dyes.

Advantages of Optical DO Probes

- They do not consume electrolyte.
- They require less frequent calibration.
- There are no membranes to replace.
- Accuracy and reliability are generally greater for optical DO probes compared to membrane probes.

Optimize the Activated Sludge Process by Facilitating Denitrification

Organisms and Their Means of Respiration

- Aerobic - use elemental oxygen
- Anoxic - use nitrate (NO_3) or nitrite (NO_2)
- Anaerobic - use other terminal electron acceptors (SO_4 , CO_2) or none at all
- Facultative - two or more means of respiration
- Fermentative - no terminal electron acceptor

Denitrification

- Heterotrophic
- Anoxic (facultative)

Pre-anoxic Denitrification: Biochemical Reaction

Sewage as carbon source:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + 10\ OH^- + NH_3$$

Factors Affecting Denitrification

- **Substrate degradability**
- pH
- **Dissolved oxygen**
- Temperature

Benefits of Denitrification

- Denitrification significantly reduces Total N loading on the receiving stream
- Denitrification generates 3.57 lb alkalinity per lb nitrate-N converted to N_2 gas
- Denitrification saves 2.86 lb oxygen per lb nitrate-N converted to N_2 gas
- Denitrification can reduce total oxygen requirements 10% to 15%

Comments about Denitrification

- Optimum pH range is 6.5 to 8.0
- Denitrification rate at 10°C is 75% of 20°C rate; Denitrification rate at 10°C is 55% of 30°C rate
- DO levels between 0 and 0.3 mg/L inhibit denitrification rates
- Complete inhibition of denitrification at DO levels > 0.3 mg/L

Impact of DO on Denitrification Rates

DO Conc, mg/L	Relative Denitrification Rate
0.0	100%
0.1	40%
0.2	20%
0.3	10%

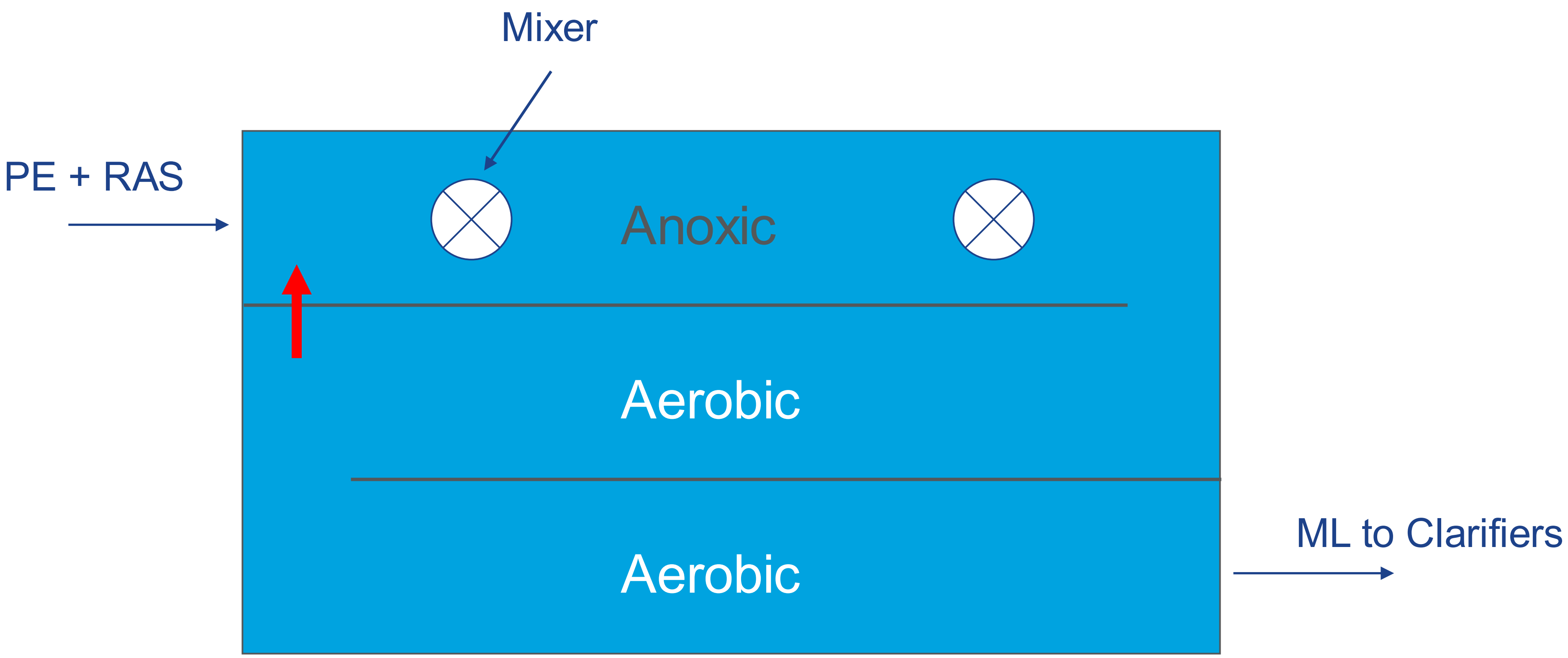
WWTP Changes to Achieve Nitrification-Denitrification

- Modify rectangular aeration basin with baffles to provide anoxic and aerobic zones
- Modify oxidation ditch to provide anoxic and aerobic zones
- Modify oxidation ditch operation with on/off aeration cycles to achieve denitrification
- Modify SBR system to include anoxic and aerobic cycles
- Modify step-feed system to include alternating anoxic and aerobic zones

Rectangular Aeration Basin Before Modification

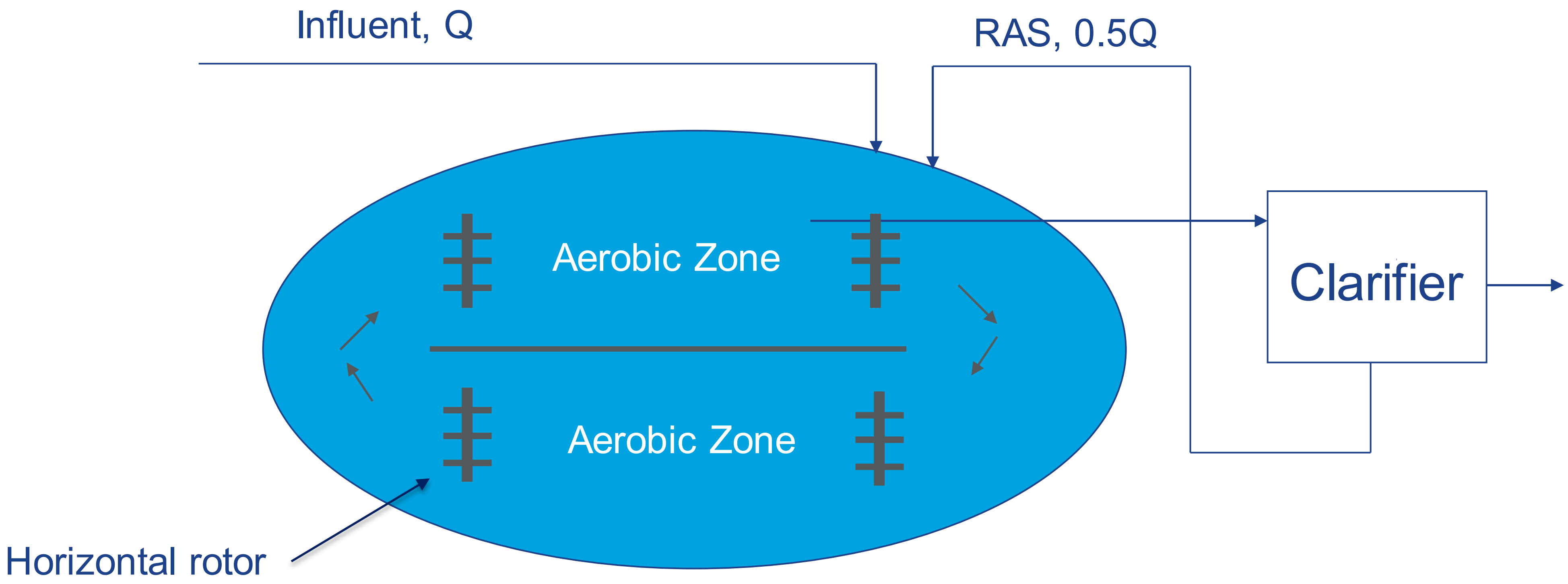
*PE is primary effluent; ML is mixed liquor

Modified Rectangular Aeration Basin

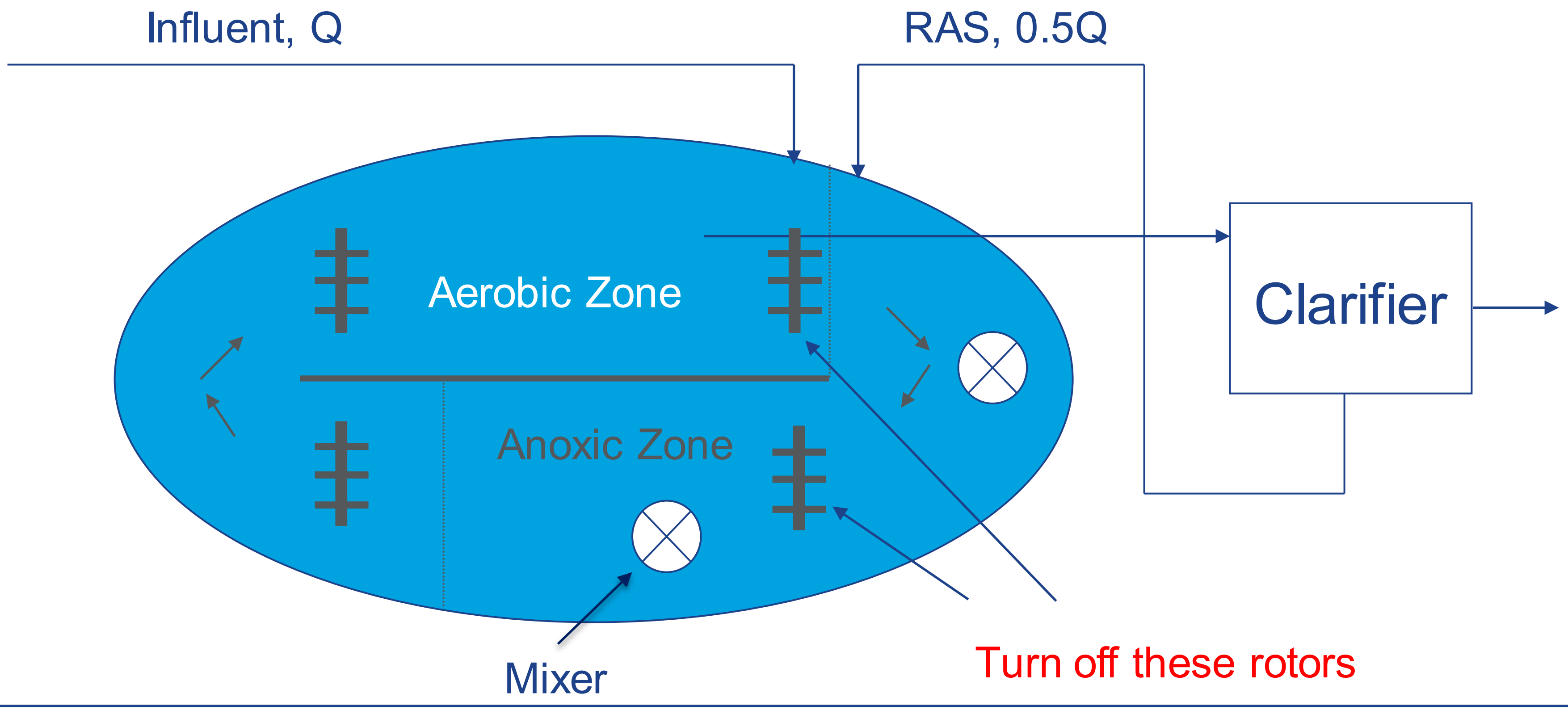


*PE is primary effluent; ML is mixed liquor

Oxidation Ditch Before Modification



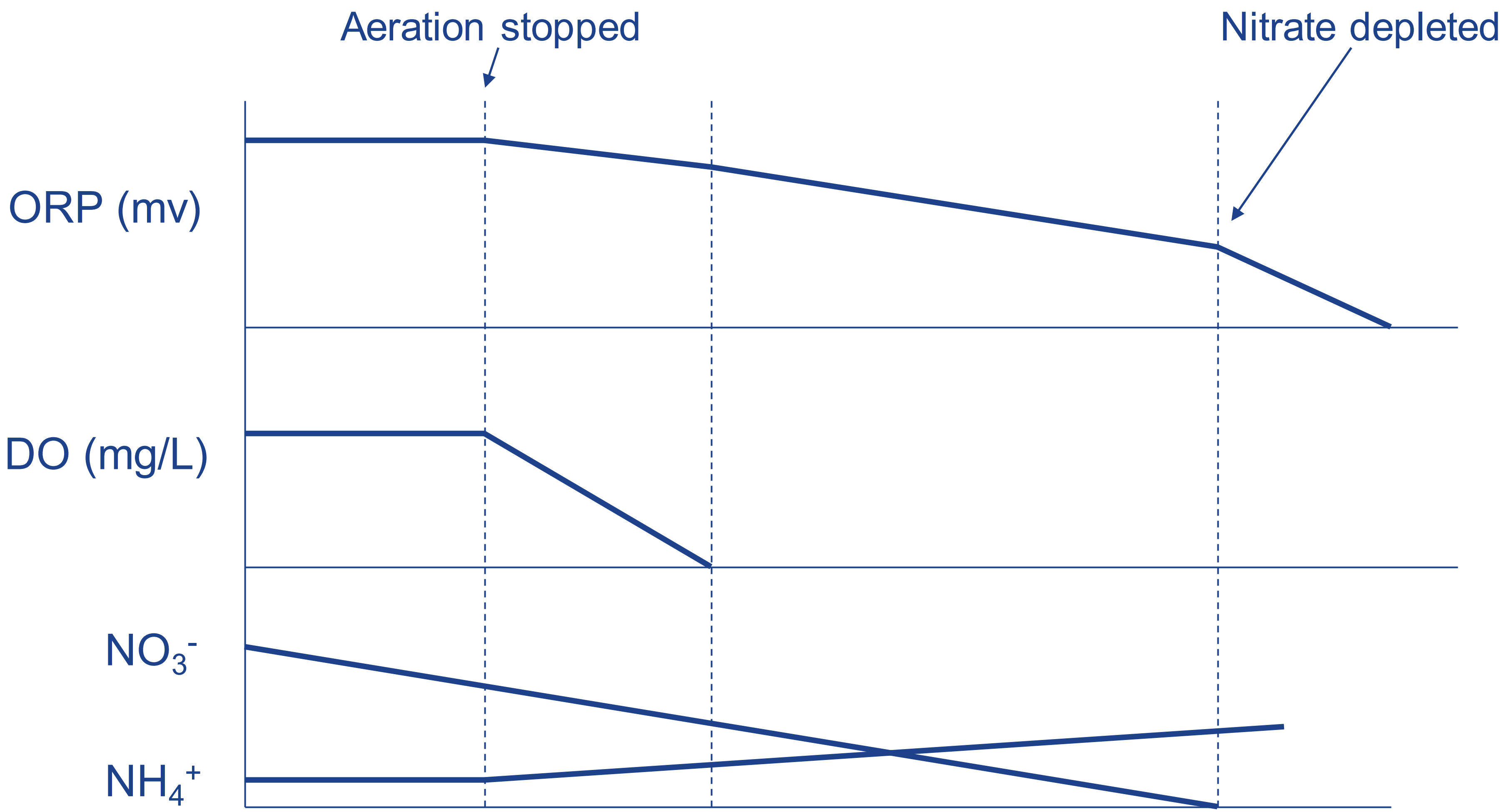
Oxidation Ditch After Modification



Intermittent Aeration for N Removal in Oxidation Ditch

- Cycle time for on/off operation of aerators may vary
- Process control with DO and ORP monitoring
- When aerator is off, may provide mixing
- During off period, oxidation ditch becomes anoxic reactor, and nitrate is converted to nitrogen gas as bacteria degrade BOD
- ORP data are used to terminate off cycle and start aeration

Change in ORP and DO in On/Off Operation



Factors Affecting On/Off Operation

- Oxidation ditch HRT
- Influent flow rate
- TKN and BOD concentrations
- Number of on/off cycles per day
- Ditch MLSS concentration

Nitrogen Removal in Oxidation Ditch

Expected Effluent Quality:

BOD_5	5 - 15 mg/L
TSS	10 - 20 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	5 - 10 mg/L
Total N	7 - 14 mg/L

Nitrogen Removal in SBRs

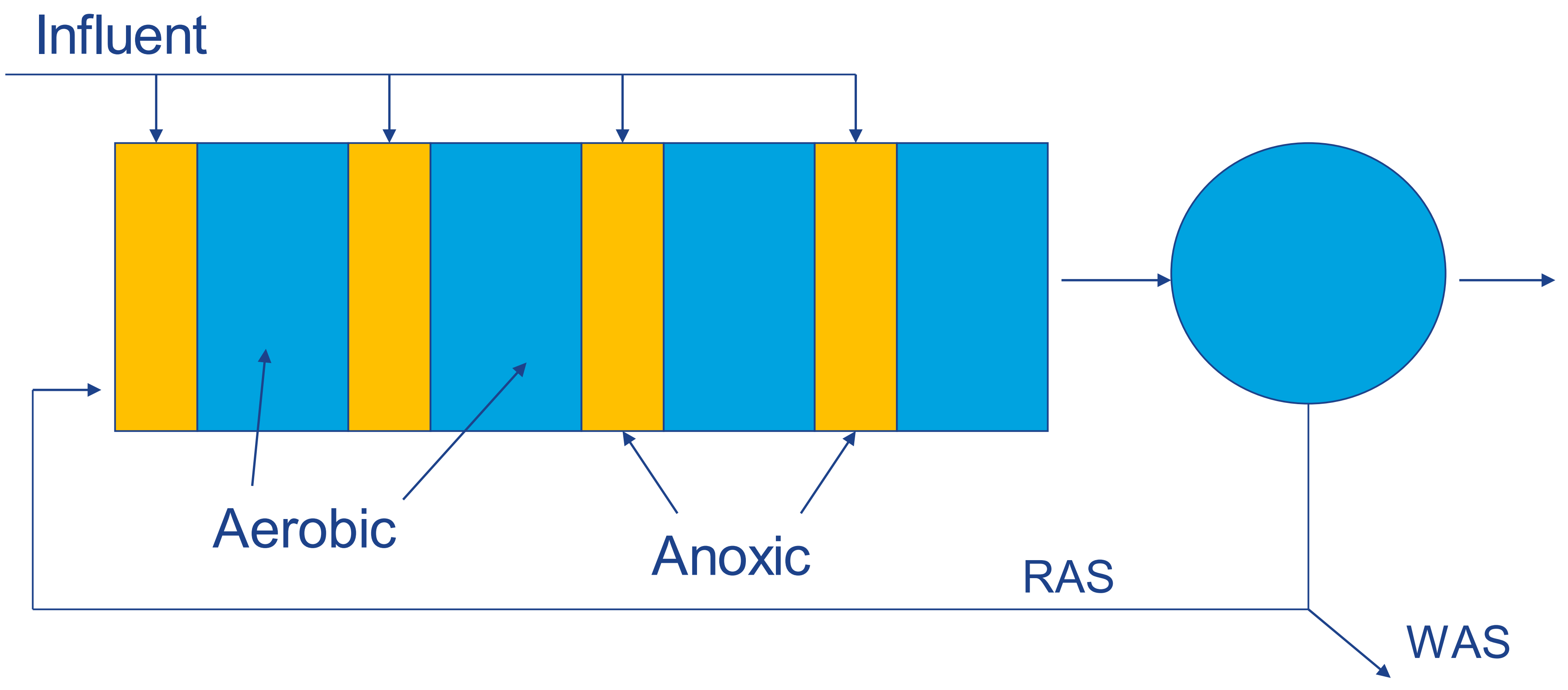
- Use anoxic and aerobic cycles to effectively remove nitrogen
- Cycles are:
  - Fill (anoxic)
  - React (aerobic/anoxic)
  - Settle
  - Decant

Nitrogen Removal in SBRs

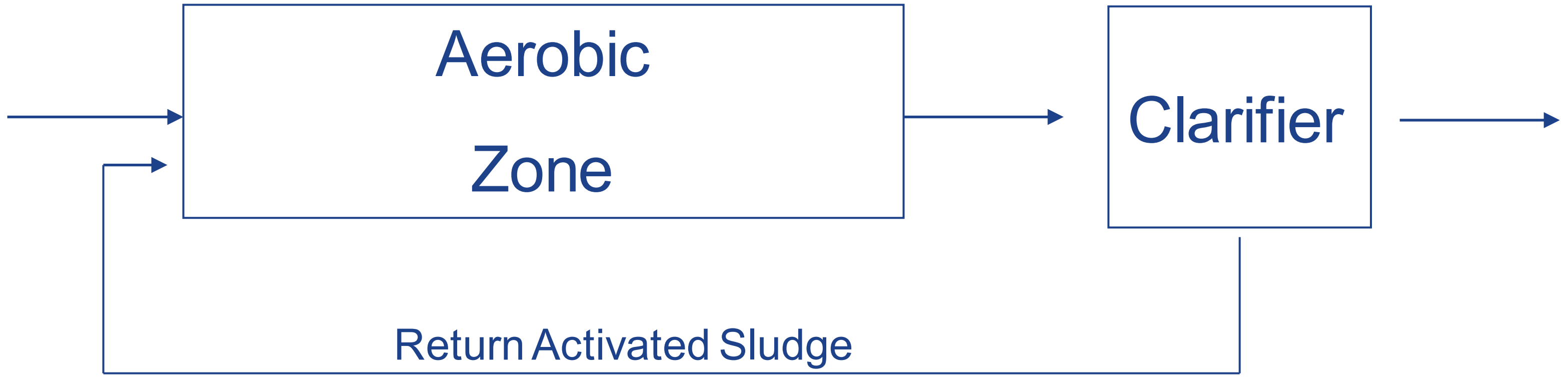
Expected Effluent Quality:

BOD_5	3 - 10 mg/L
TSS	5 - 15 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	3 - 10 mg/L
Total N	5 - 12 mg/L

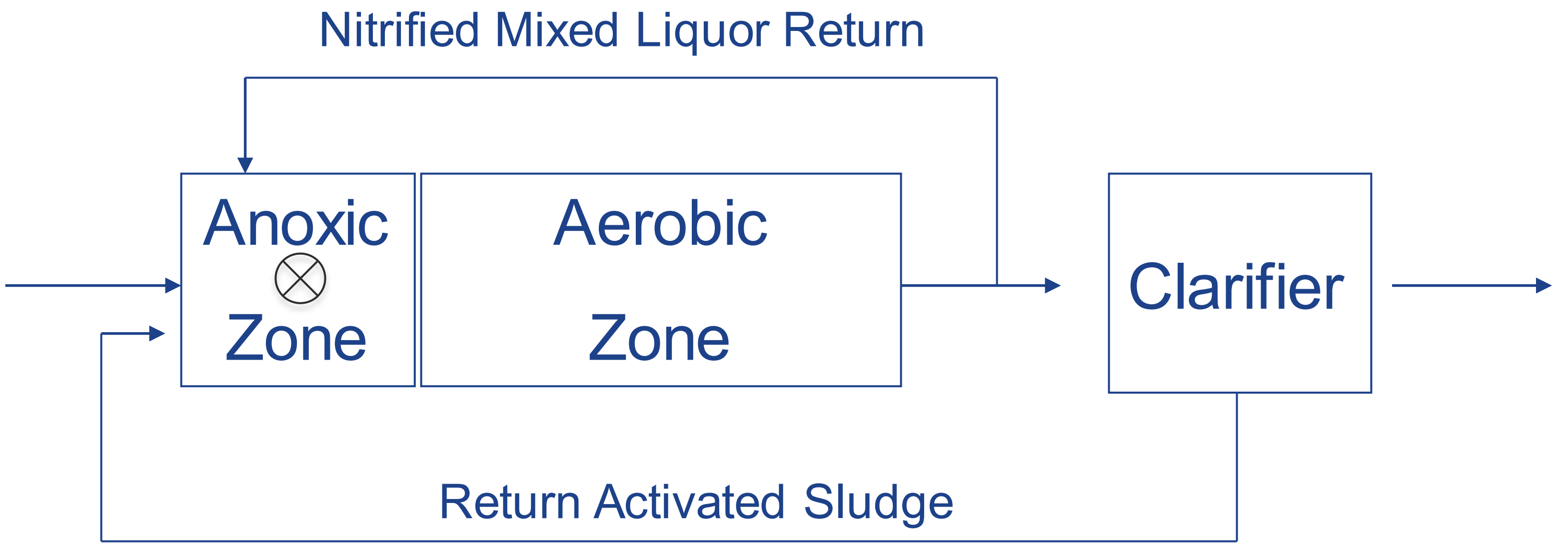
N Removal in Step-Feed Process



Conventional Activated Sludge



Add an Anoxic Zone using Baffle, Mixed Liquor Return, and Mixing



Before and After Effluent Quality

Effluent Quality:

	Before	After
BOD_5	5 - 25 mg/L	5 - 15 mg/L
TSS	10 - 25 mg/L	10 - 20 mg/L
Ammonia-N	1 - 5 mg/L	1 - 2 mg/L
NO_x-N	8 - 15 mg/L	3 - 9 mg/L
Total N	10 - 20 mg/L	5 - 12 mg/L
*SVI	125 - 225	50 – 125

* impacts on mixed liquor at one facility

Principles in Implementing N Removal

- Consider a wide variety of alternatives
  - adding anoxic zone
  - adding anoxic denitrifying filter
  - adding anoxic moving bed reactor
- Invest in plant-specific waste characterization data
- Engineer and operators should discuss changes
- Tailor to specific plant situation
- Balance risk and cost

Thank you!

For Questions or Comments please reach out to the following:

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