Better Plants
U.S. DEPARTMENT OF ENERGY

Webinar #1 for IAC Directors: Introduction to Biological Wastewater Treatment

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Intro to Biological Wastewater Treatment

- Objectives
- Definitions
- Role of Microorganisms
- Activated Sludge Processes
- Biological Nitrogen & Phosphorus Removal

*References: Metcalf & Eddy, 4th edition
WEF training materials

Objectives

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

Biological Treatment

- Duplicates nature's process of stream purification
- Uses naturally occurring microorganisms
- Adapted in controlled facilities to specific conditions and time restraints
- Used to treat compatible and incompatible pollutants

Critical Aspects of Biological Treatment

- Proper nutrient balance
  - Macronutrients (N and P)
  - Micronutrients (K, Ca, S, Cl, etc.)
- General rule: BOD/N/P = 100/5/1
- Maintain acceptable pH range (6-9)
- Maintain acceptable temperature
- Avoid toxic substances at levels that will inhibit or interfere with microbes

Definitions: Metabolic Functions

- **Aerobic processes** – biological treatment processes that occur in the presence of oxygen
- **Anaerobic processes** – biological treatment processes that occur in the absence of oxygen
- **Anoxic processes** – process by which nitrate-N is converted biologically to nitrogen gas in the absence of oxygen

Definitions: Metabolic Functions (continued)

- **Facultative processes** – biological treatment processes in which the organisms can function in the presence or absence of molecular oxygen
- **Combined aerobic/anoxic/anaerobic processes** – processes grouped together achieve a specific treatment objectives

Definitions: Treatment Processes

- **Suspended-growth processes** – biological treatment processes in which the microbes responsible for the conversion of organic matter or other constituents in the wastewater to gases and cell tissue are maintained in the suspension within the liquid

- **Attached-growth processes** – BTPS in which the microbes are attached to some insert medium (rock, plastic, etc.). They are also known as fixed-film processes.

- **Lagoon Processes** – treatment processes that take place in ponds or lagoons with various aspect ratios and depths

Definitions: Treatment Functions

- **Biological nutrient removal** – removal of N and P in biological treatment processes
- **Biological phosphorus removal** – biological removal of P by accumulation in biomass and subsequent solids separation
- **Carbonaceous BOD (CBOD) removal** – biological conversion of carbonaceous organic matter to cell tissue and various gaseous end products

Definitions: Treatment Functions

- **Nitrification** – two-step biological process by which ammonia-N is converted to nitrite-N and then to nitrate-N; this exerts oxygen demand known as NBOD.

- **Denitrification** – biological process by which nitrate-N is reduced to nitrogen and other gaseous end products

Definitions: Treatment Functions

- **Stabilization** – biological process by which organic matter in waste sludges is stabilized, usually by conversion to gases and cell tissue (aerobic and anaerobic digestion)

- **Substrate** – the organic matter or nutrients that are converted during biological treatment or that may be limiting in biological treatment (e.g., carbonaceous organic matter in wastewater)

Roles of Microbes in Wastewater Treatment

- **Oxidation of organic matter** in wastewater is accomplished biologically using a variety of microorganisms, primarily bacteria

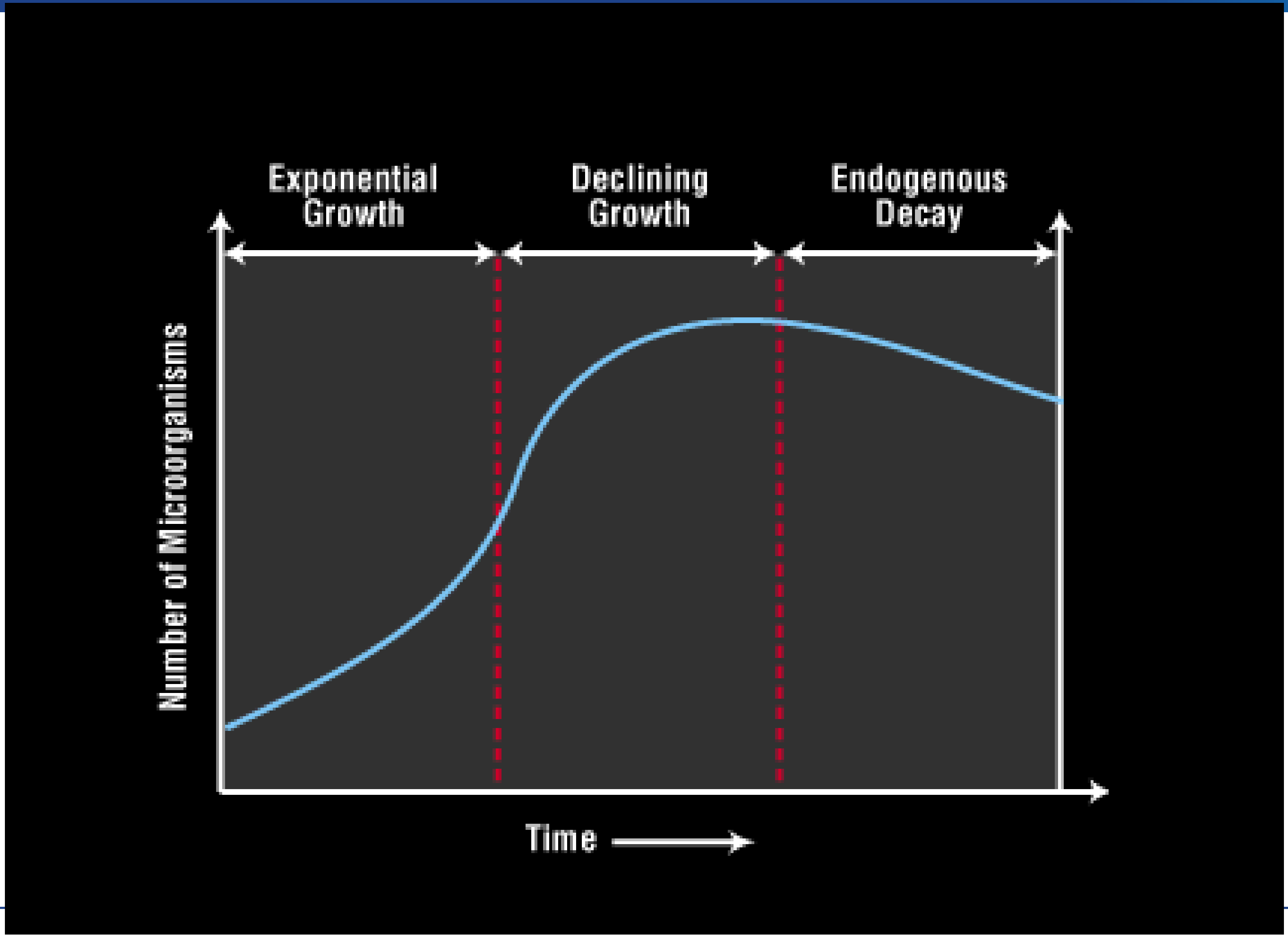
$$\text{Organics} + O_2 + NH_3 + PO_4 \xrightarrow{\text{microbes}} \text{New cells} + CO_2 + H_2O + \text{Energy}$$

- New cells are produced by the **synthesis reaction** (biomass produced as a result of consumption of organic matter)

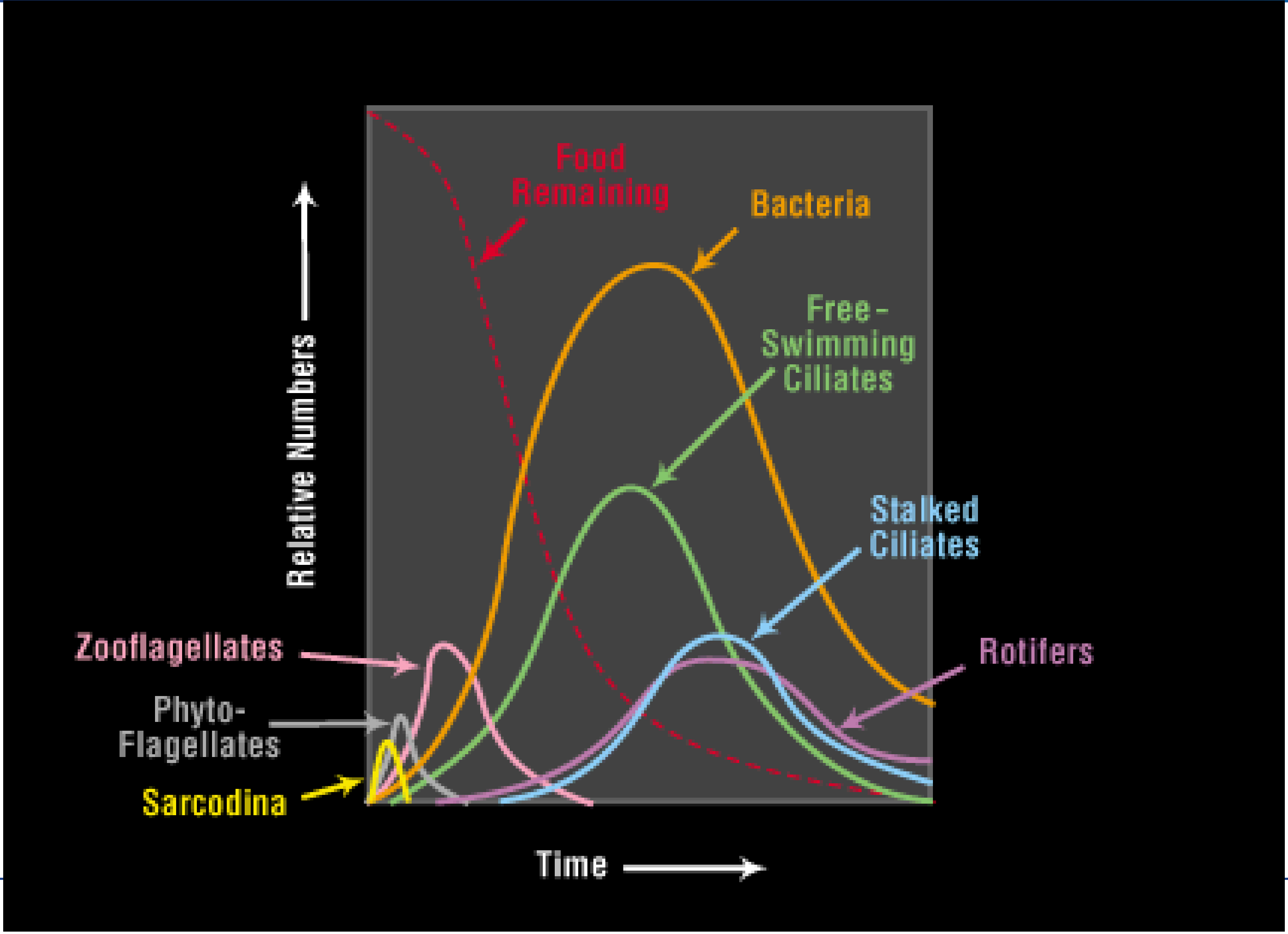
Roles of Microbes in Wastewater Treatment

- Microbes are also used to remove N and P in wastewater treatment processes
- Nitrifying bacteria can convert ammonia-N to nitrite-N and nitrate-N
- Denitrifying bacteria can convert nitrate-N to gaseous nitrogen
- In biological P removal, bacteria take up and store large amounts of inorganic P

Three Phases of Microorganism Life Cycle



Distribution of Microbes in Activated Sludge



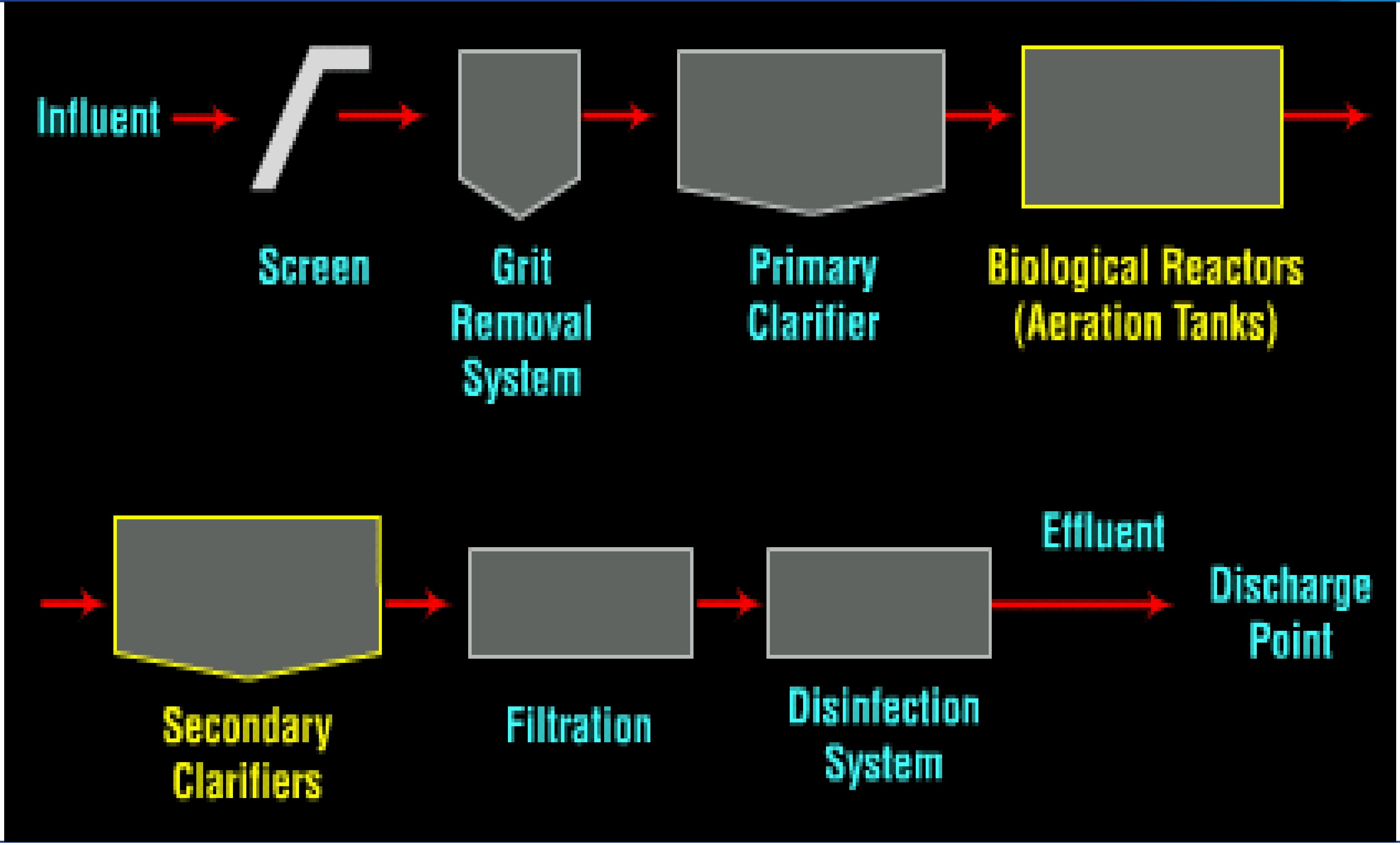
Biological Processes: Activated Sludge

- Continuous-flow or batch, biological treatment process in which a suspension of aerobic and facultative microbes are maintained in a relatively homogenous state by the mixing and turbulence created by aeration equipment
- Microorganisms typically oxidize soluble and colloidal organic matter to CO_2 and H_2O in the presence of molecular oxygen
- Biomass is settled in final clarifier with most biomass returned to the aeration tanks, while some biomass is wasted from the process

Basic Activated Sludge Process Components

- Influent pretreatment
- Aeration basin
- Secondary clarification
- Return activated sludge
- Waste activated sludge

Wastewater Process Diagram Highlighting the Activated Sludge Process Units (yellow)



Primary Components of Activated Sludge

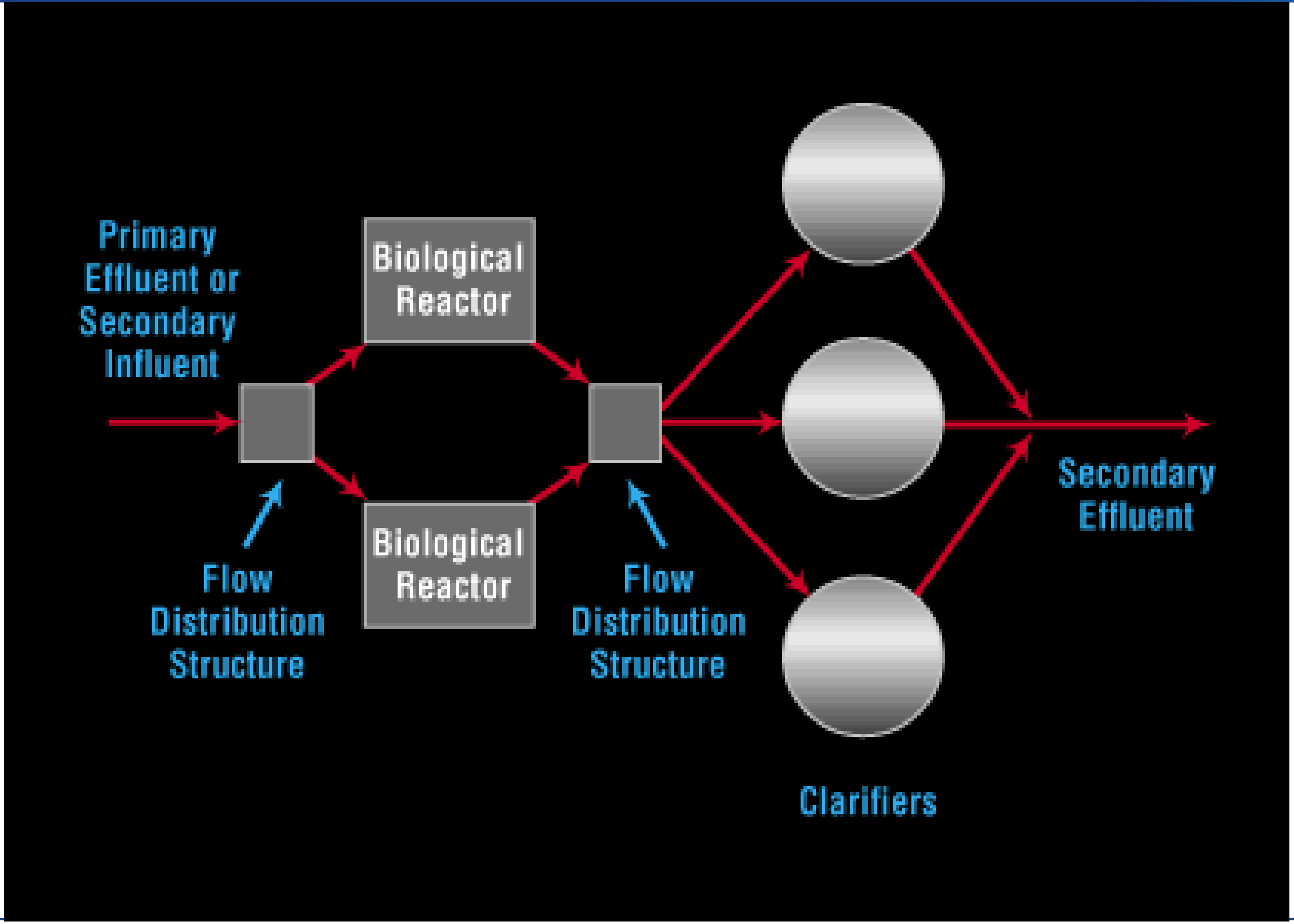
Biological Reactors - The tanks where aerobic, anaerobic, or anoxic conditions are created to produce healthy mixed liquor and facilitate biological treatment processes.

Clarifiers - Sedimentation tanks used to remove settleable solids in wastewater.

Biological Reactor with Diffused Aeration

Surface Aeration at an Activated Sludge Facility

Flow Diagram for Activated Sludge Process



Activated Sludge Reactor

Mixed Liquor – A mixture of raw or settled wastewater and activated sludge contained in an aeration tank or biological reactor.

Mixed Liquor Volatile Suspended Solids (MLVSS) – The concentration (mg/L) of volatile suspended solids in activated sludge mixed liquor … a good indicator of biomass concentration.

Options for Activated Sludge Process Control

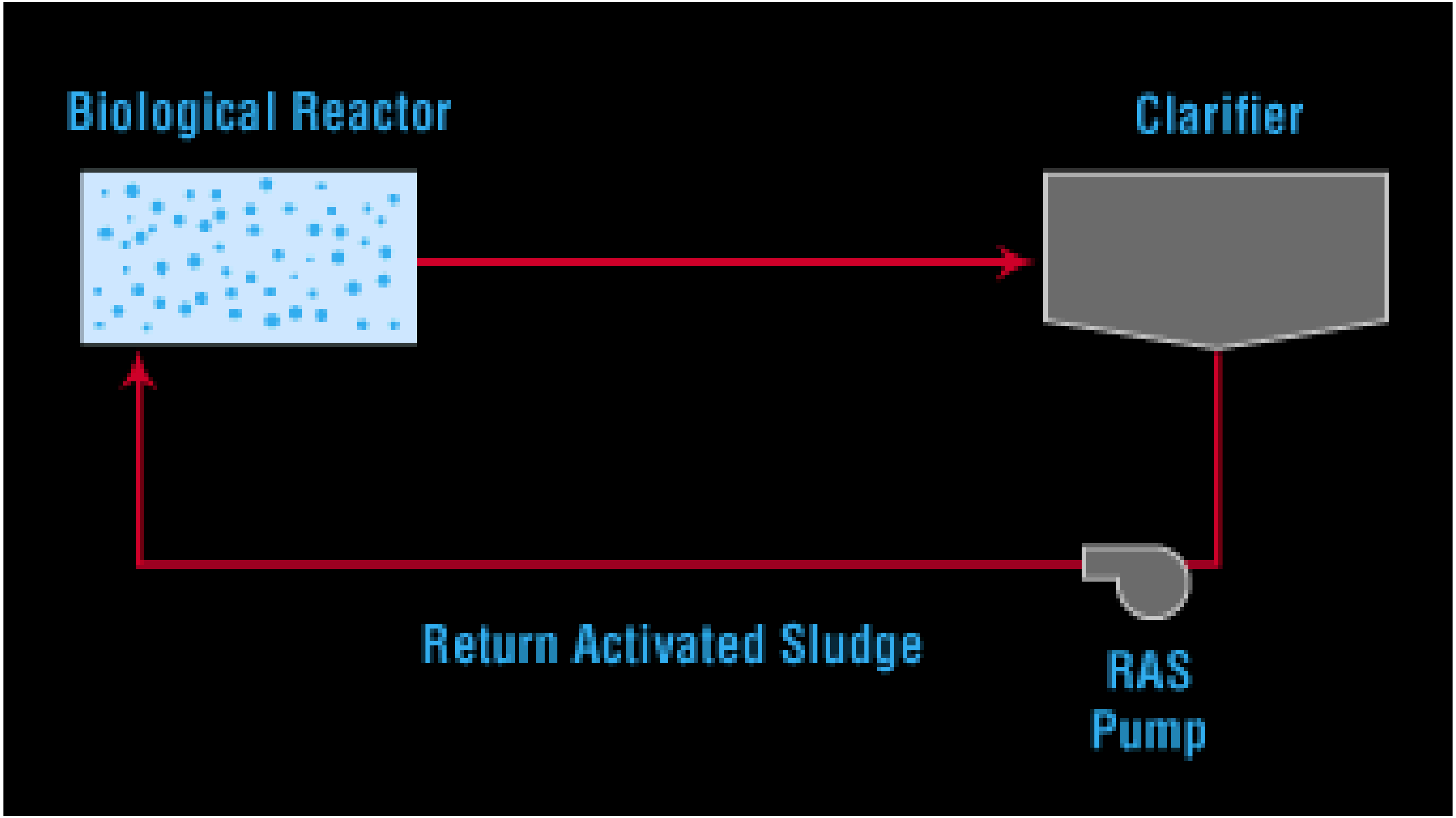
1. **Mixed Liquor Suspended Solids (MLSS)** – The concentration (mg/L) of suspended solids in activated sludge mixed liquor.

2. **Sludge Age** – The average time (days) a microbial cell remains in the activated sludge system (MCRT or SRT)

3. **Solids Inventory** – The mass of suspended solids contained in the reactor and in the bottom of the final clarifier

4. **Food-to-Microorganism Ratio** – The pounds of BOD_5 per day applied to the reactor divided by the pounds of MLVSS in the reactor.

Biological Reactor and Micrograph of Floc Particle



Return activated sludge (RAS) is recycled back to the biological reactor.

Secondary clarifiers are used to settle the mixed liquor solids.

High Rate Activated Sludge

- High food/microorganism (F/M) ratio
- Short detention time in aeration tank
- High volumetric loading
- Low sludge age
- Poor bio-flocculation
- Low BOD removal efficiency
- Not good for municipal WWTP but may be useful for roughing treatment at the industry

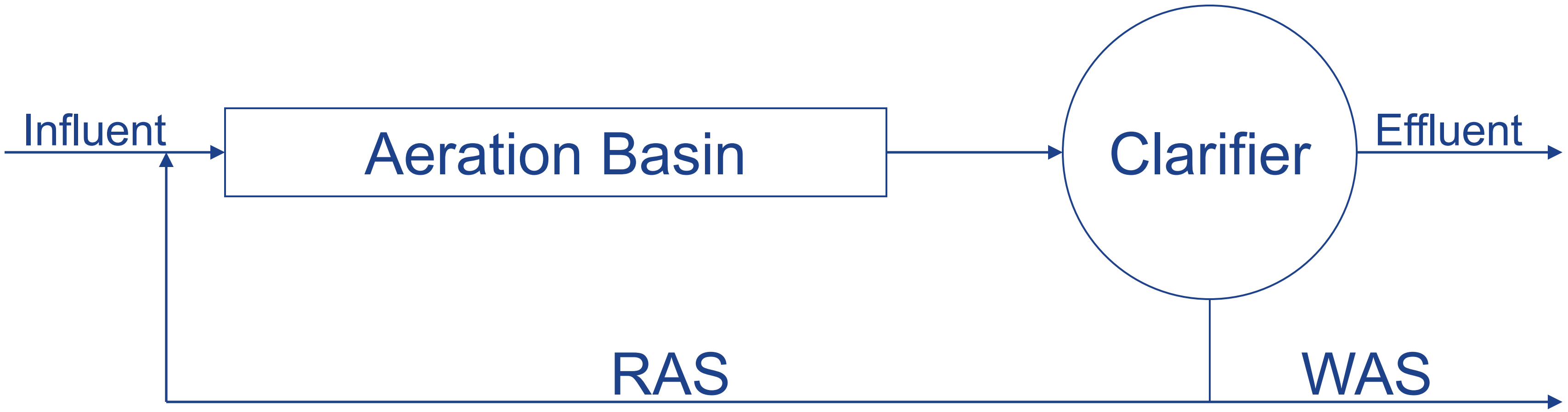
Conventional Activated Sludge

- Moderate F/M ratio
- Moderate aeration time (4 to 8 hours)
- Moderate sludge age (5 to 15 days)
- Good bio-flocculation
- Good settling sludge
- Good effluent quality

Conventional Activated Sludge

- Plug flow
- Complete mix
- Step feed
- Contact stabilization
- Pure oxygen

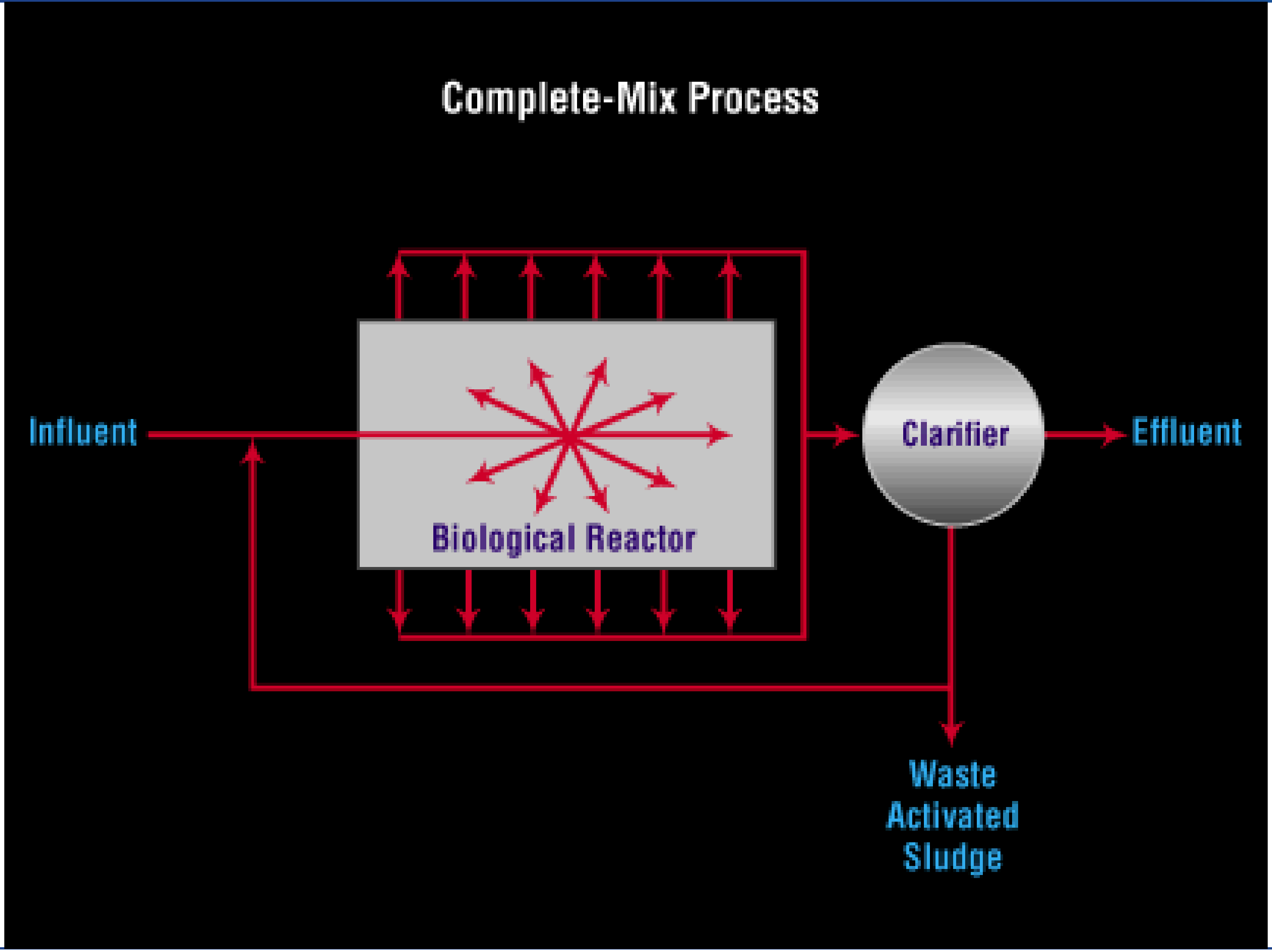
Conventional Plug Flow Activated Sludge



Plug Flow Activated Sludge

- Susceptible to shock loading
- Uneven O_2 uptake rate
- Low DO at front end of tank
- Most efficient type of reactor
- Short circuiting is not a problem

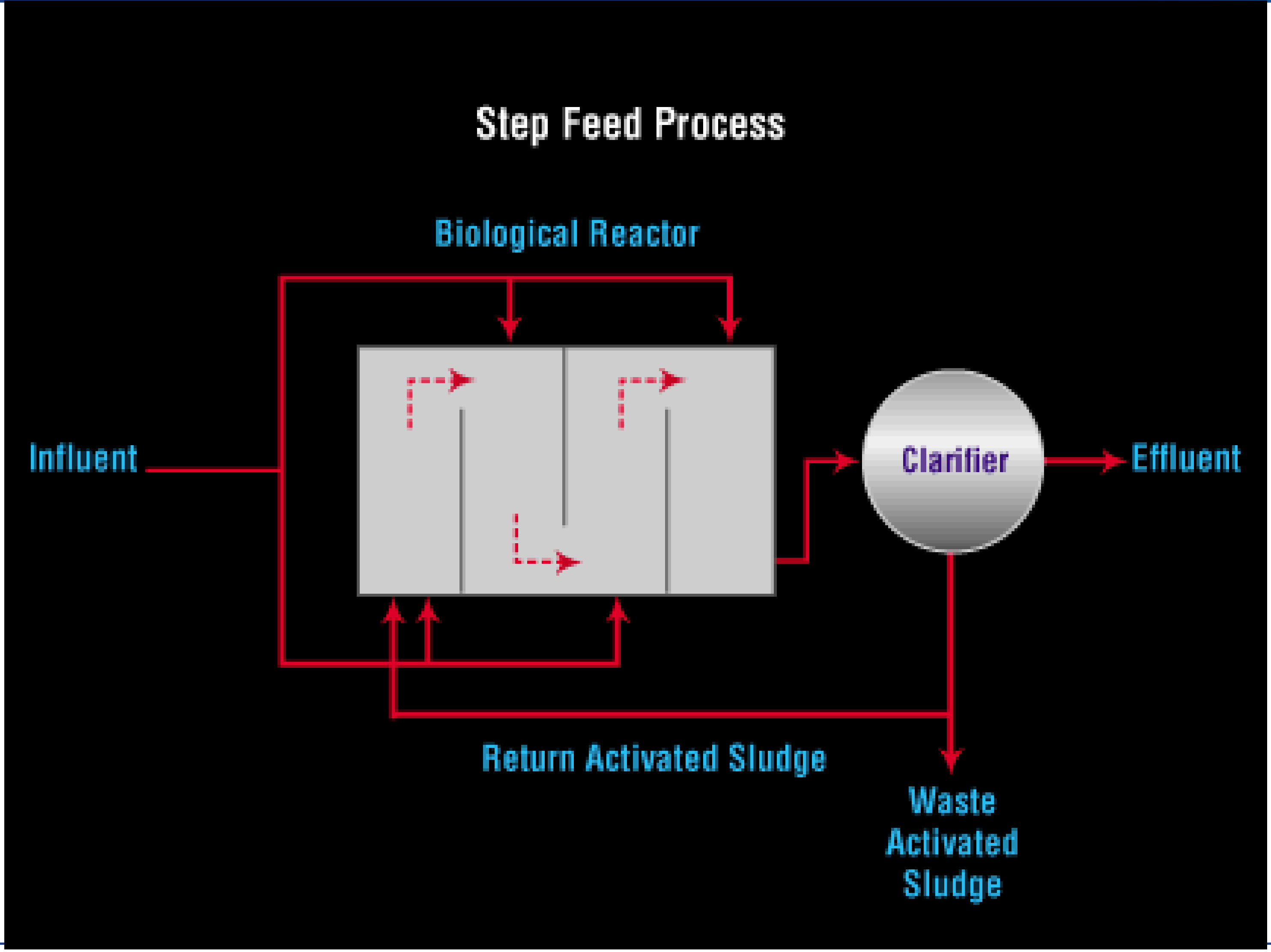
Complete-Mix Activated Sludge



Complete Mix Activated Sludge

- Uniform organic load on the aeration tank
- Uniform MLSS concentration
- Uniform oxygen demand
- Can handle shock loads well
- Susceptible to short circuiting
- Not as efficient as a plug flow reactor
- Susceptible to filamentous bulking problems

Step Feed Activated Sludge



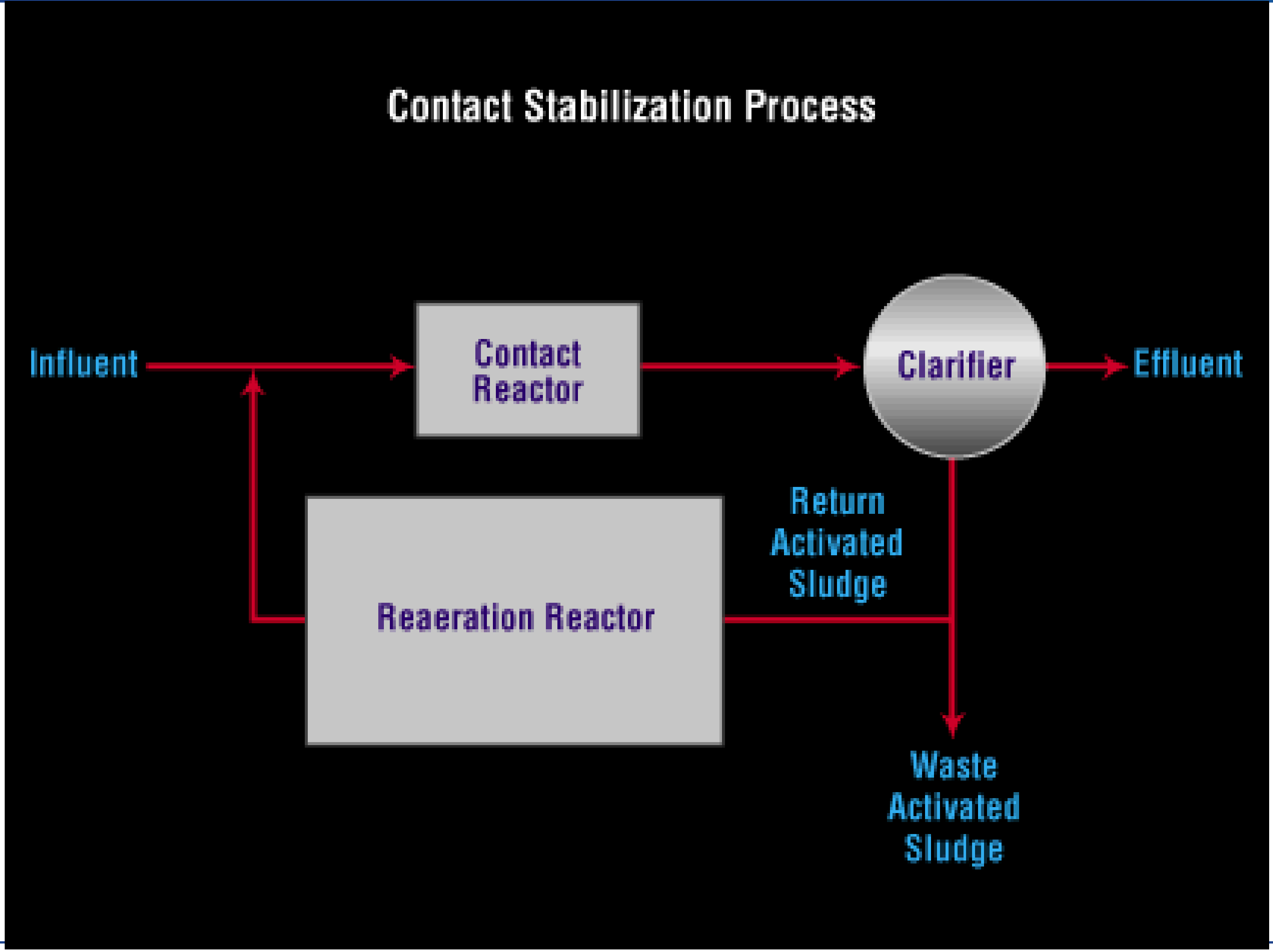
Step Feed Activated Sludge

- Evens out the oxygen demand somewhat
- Provides good flexibility
- Can carry a higher solids inventory
- Can operate at a higher organic loading rate

Step Feed Activated Sludge

- Can be operated as contact stabilization by feeding only the last zone
- Can be operated as plug flow by feeding only the first zone
- High wet-weather flows can be bypassed to the last zone to minimize solids loading on final clarifier
- Short circuiting and incomplete hydrolysis of particulate substrate may occur

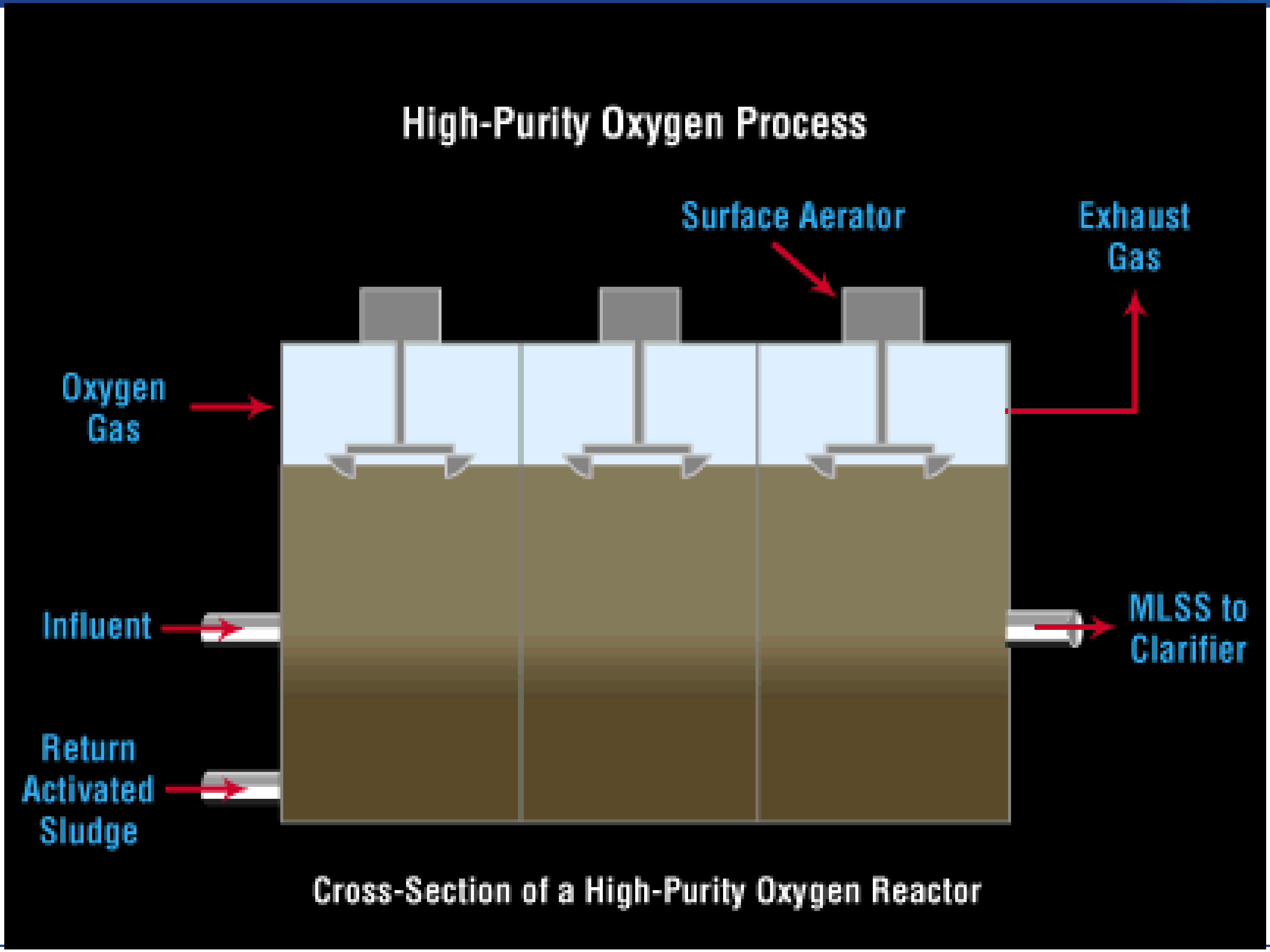
Contact Stabilization Activated Sludge



Contact Stabilization Activated Sludge

- Rapid removal of soluble BOD occurs in the contact zone
- Colloidal and particulate organics are adsorbed in the contact zone for degradation later in the stabilization zone
- Requires much less volume than complete-mix or plug-flow processes (cost-effective)
- Not good where nitrification is needed
- Susceptible to hydraulic shock loading

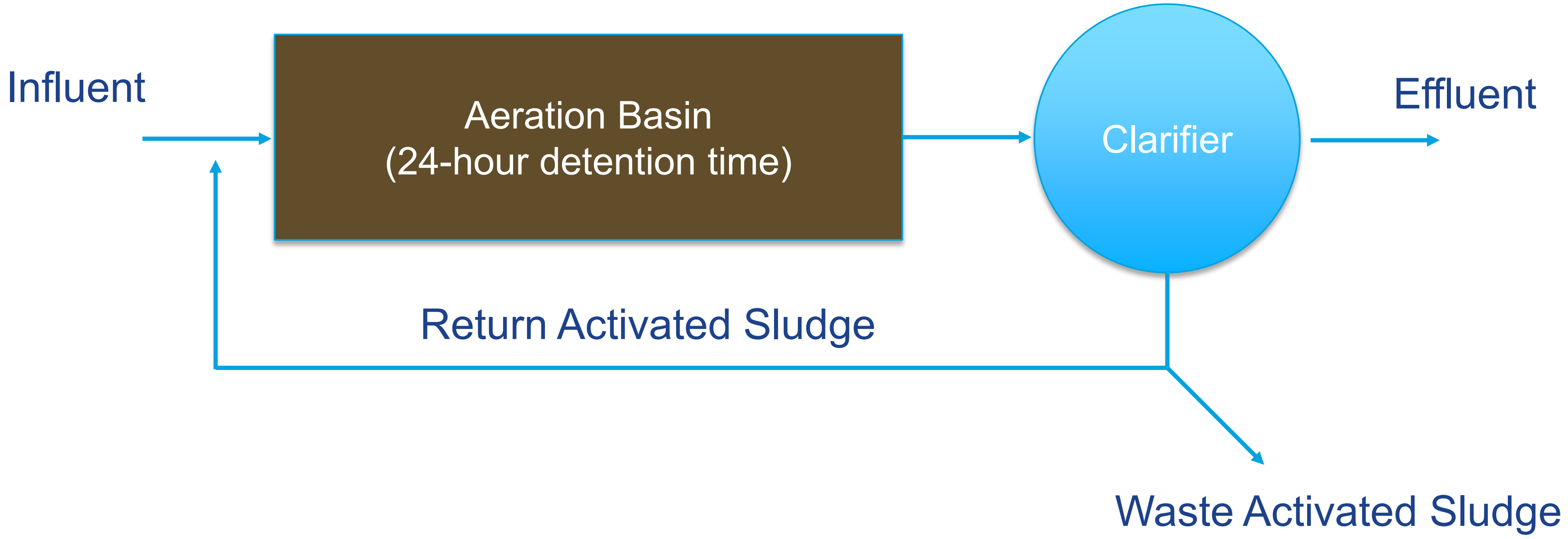
Pure Oxygen Activated Sludge



Pure Oxygen Activated Sludge

- Higher oxygen transfer rates
- Can operate at higher MLSS levels
- Can operate at shorter detention time
- Requires less space
- Rate of oxygen addition is 2 to 3 times greater than conventional processes
- More complex because of on-site O_2 generation
- Nitrification ability is limited because of CO_2 buildup (pH $\leq$ 6.5)
- High capital and operating costs

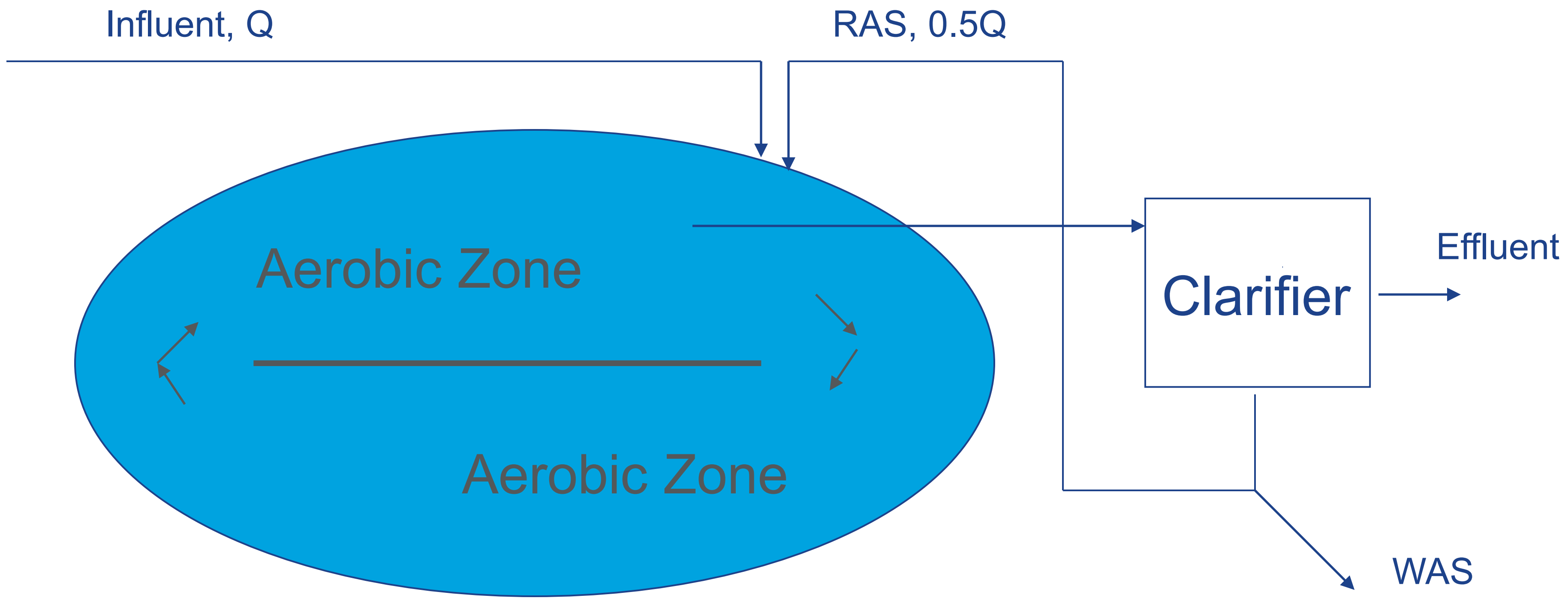
Extended Aeration Activated Sludge



Extended Aeration (Low Rate) Activated Sludge

- Excellent BOD removal efficiency
- Relatively good bio-flocculation
- Long aeration detention time ($\approx$ 24 hours)
- Low F/M ratio
- Long sludge age (20 to 40 days)
- Low volumetric organic loading
- Achieves excellent nitrification

Oxidation Ditch



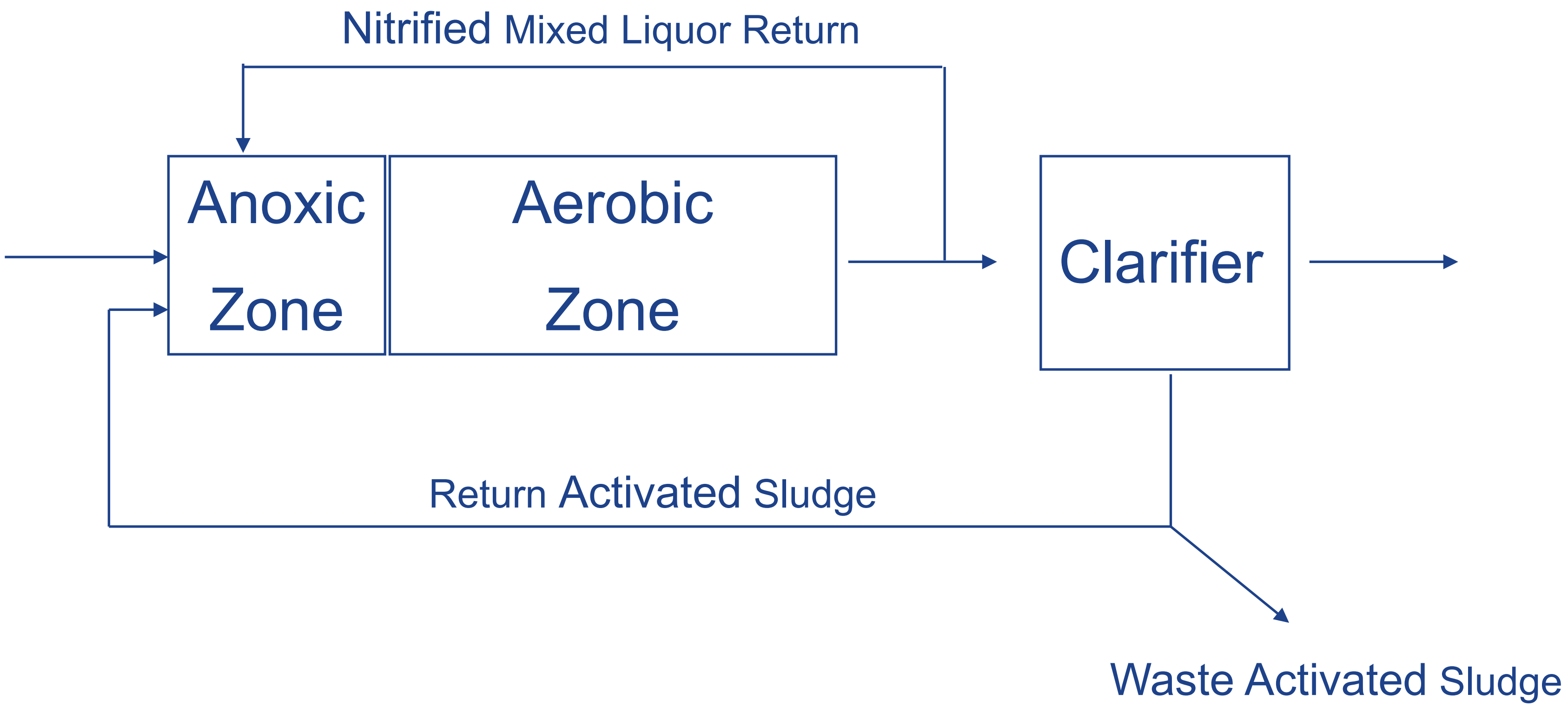
Sequencing Batch Reactors

- Fill-and-draw type of activated sludge
- Aeration and settling are performed in the same tank
- Five steps in operation:
  (1) Fill
  (2) React (aeration)
  (3) Settle
  (4) Decant*
  (5) Idle*
    * sludge wasting in this step

Activated Sludge for N Removal

- Use anoxic zone to promote denitrification
- Better to have anoxic zone ahead of aerobic zone
- DO levels need to be ≤ 0.3 mg/L
- Readily degradable organic substrate is preferred as carbon source
- At low or zero DO, facultative heterotrophs use nitrite-N and nitrate-N as electron acceptor

Biological Nitrification/Denitrification



Activated Sludge for N Removal

- Nitrite-N and nitrate-N are converted to nitrogen gas in the anoxic zone.
- Denitrification produces one-half the alkalinity consumed during nitrification.
- Simultaneous nitrification and denitrification can be achieved at DO levels between 0.0 and 0.3 mg/L.
- For anoxic zone ahead of aerobic zone, it is essential to recycle mixed liquor (2Q to 4Q) from end to aerobic zone to front of anoxic zone.

Activated Sludge for N Removal

- Anoxic zone can be placed after aerobic zone, but this approach is less efficient
- Denitrification rate is directly proportional to level of organics available and inversely proportional to DO levels
- Denitrification rate does not depend on nitrate-N concentration

Activated Sludge for P Removal

- Need an anaerobic zone ahead of the aerobic zone to promote P removal
- Under anaerobic conditions, certain bacteria will take up organics and store them as polyhydroxybutyrate (PHB) and release P into solution
- In the subsequent aerobic zone, the stored PHB is rapidly oxidized with significant uptake of dissolved P into cell mass

Activated Sludge for P Removal

- Most of the P will be removed from the process in the waste biomass

- Where N and P removal are required, the sequence of bioreactors may be anaerobic/anoxic/aerobic, anaerobic/anoxic/aerobic/anoxic/aerobic, etc., to achieve the desired metabolism and desired effluent quality

Thank you!

For Questions or Comments please reach out to the following:

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