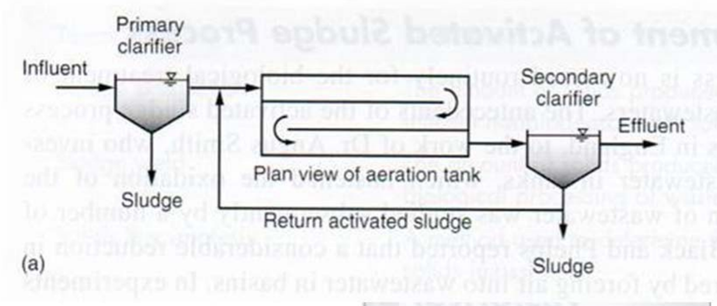
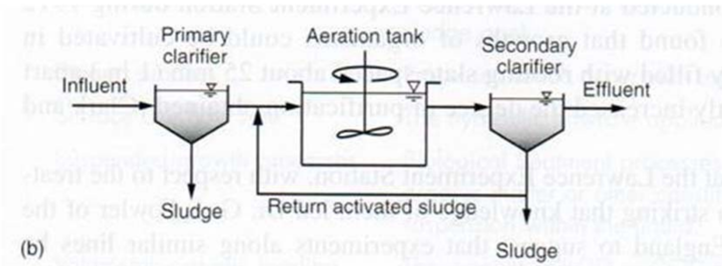
Practical applications of biological treatment

Evolution of conventional AS processes

- **Plug-flow process configuration**
  - In earlier applications (1920s-1970s), plug-flow reactors were most common
  - Significant toxic effects because of industrial wastes observed

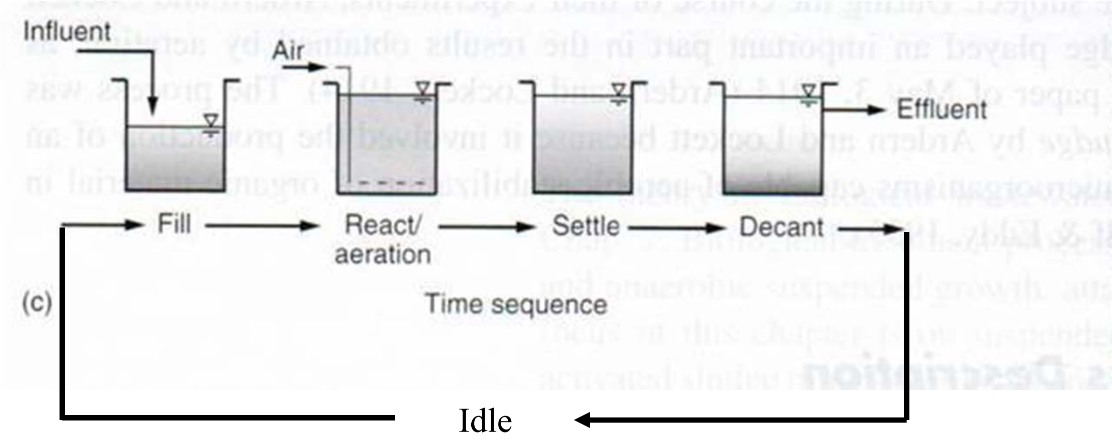




- **Complete-mix process configuration**
  - Dilution in the reactor → much less toxic effects
  - Single-stage, complete-mix activated sludge (CMAS) process common in 1970s and early 1980s

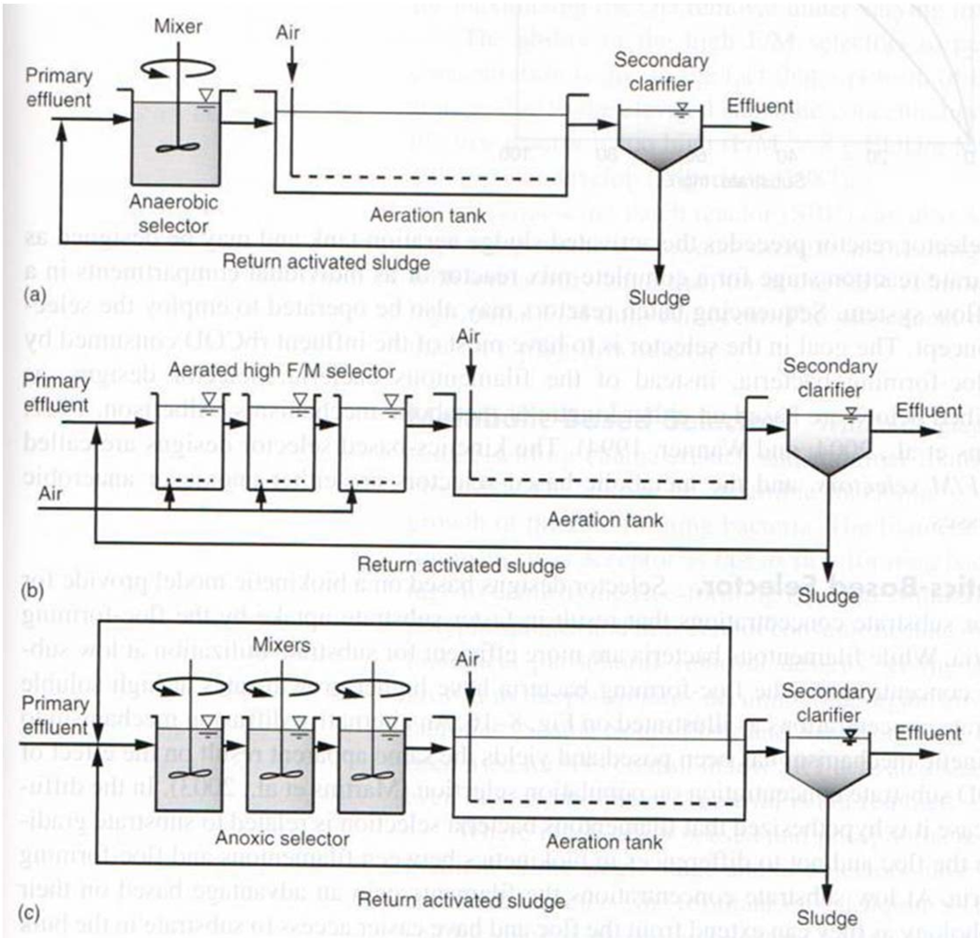
Evolution of conventional AS processes

- **Sequencing batch process configuration**
  - Fill-and-draw system, no separate sedimentation tank
  - Five stages: Fill – React – Settle – Decant - Idle
  - Usually for small communities and industry with intermittent flows
  - Increased applications in larger cities these days



Evolution of conventional AS processes

- **Development of selectors**
  - Place small tank(s) in front of the aeration tank
  - Usually to improve the settling properties of activated sludge
  - The selectors provide conditions to biologically select activated sludge of better settling property



Evolution of conventional AS processes

- **Development of selectors**

  1) High F/M selectors

     - Filamentous bacteria are more efficient at low substrate conc. while floc-forming bacteria have higher growth rates at high substrate conc.

  2) Anoxic or anaerobic selectors

     - Floc-forming bacteria are better at using nitrate or nitrite as electron acceptors than filamentous bacteria
     - PAOs have good settling property – anaerobic selector makes PAOs more competitive than filamentous bacteria

Evolution of conventional AS processes

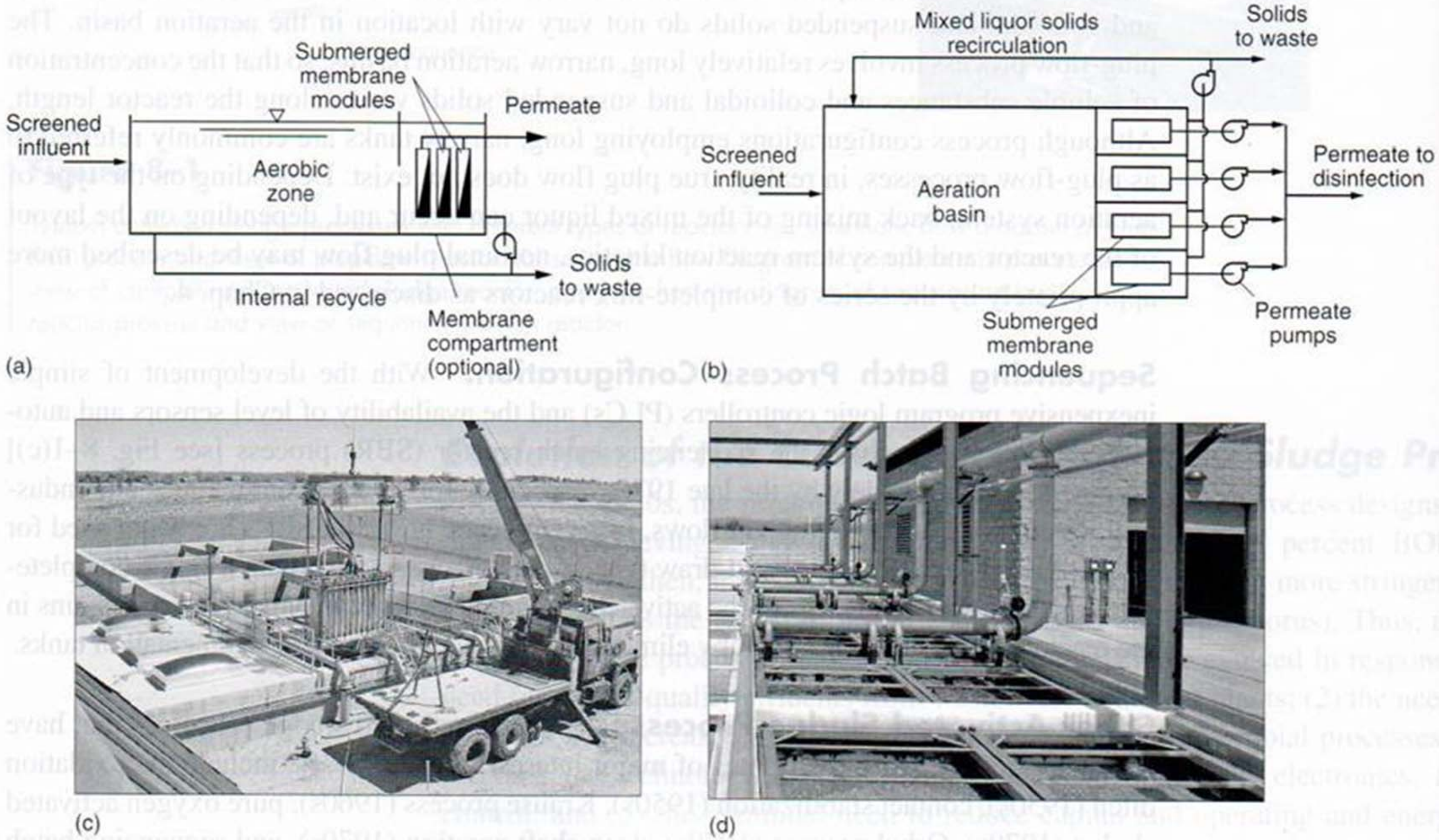


Figure 8–2

Membrane bioreactor (MBR). A multi-staged activated sludge system with membranes for liquid-solids separation: (a) section through MBR with separate compartment for the membranes, (b) plan view of MBR, (c) view of membrane cassettes being placed in separate compartment, and (d) view of separate membrane compartment.

MBR process

- Use membrane for solid/liquid separation
- Microfiltration or ultrafiltration membrane immersed directly into the reactor
- Membrane fouling a major concern: became feasible with advances in membrane manufacturing & configuration technique

MBR process

- **Advantage**
  - Can maintain high biomass concentration → much higher volumetric organic loading rate → much smaller reactor size requirement
  - No need for separate clarifier → additional area saving
  - Simpler process operation with no concerns about activated sludge settling properties
  - Better effluent quality through membrane separation
  - Lower disinfectant dose requirement for the following disinfection unit because of low turbidity effluent

- **Disadvantage**
  - Energy cost for membrane filtration
  - Need for membrane replacement
  - Operational demands for fouling control

Settling problems: bulking sludge

- **Bulking sludge**
  - Sludge blanket not stable; large quantities of MLSS carried along with the clarifier effluent
  - Exceeding the effluent standard for SS & BOD/COD
  - Two principal types of sludge bulking
    - Filamentous bulking: growth of filamentous organisms
    - Viscous bulking: production of excessive amount of extracellular biopolymer

Filamentous vs. viscous bulking

- **Filamentous bulking**
  - Bacteria form filaments of single-cell organisms that attach end-to-end, and the filaments protrude out of the sludge floc
  - Filamentous bacteria are competitive at low DO, low organic conc., low nutrient conc. → need control of these variables!

- **Viscous bulking**
  - Results in a sludge with a slimy, jellylike consistency
  - Biopolymers are hydrophilic → contains significant amount of water in the floc → low density, poor compaction
  - Found at nutrient-limited systems and at a very high F/M ratio

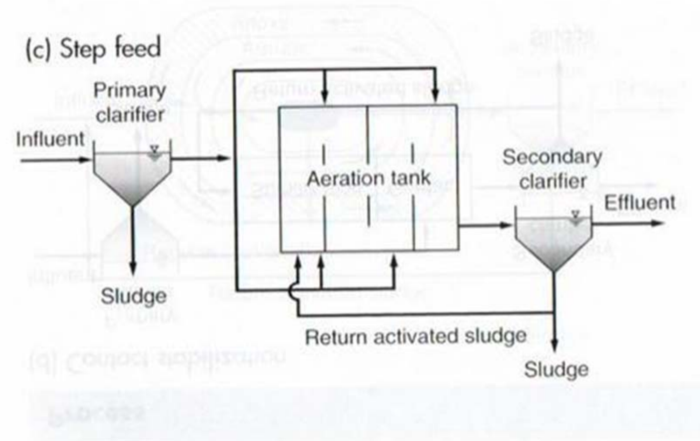
Settling problems: Nocardioform foam

- **Nocardioform foam**
  - "Nocardioform" bacteria have hydrophobic cell surfaces and attach to air bubbles, causing foaming
  - Thick foam (0.5~1 m) of brown color forms
  - Can occur in diffused aeration systems and also in anaerobic treatment systems
  - Major solutions
    - Avoid trapping foam in the aeration tank effluent
    - Surface wasting of activated sludge
    - Avoid the recycle of skimmings

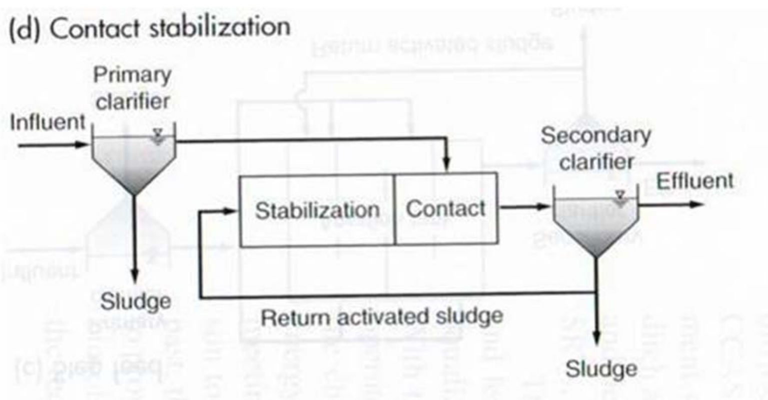
Settling problem: rising sludge

- **Rising sludge**
  - Rising of sludge having relatively good settling properties due to gas formation
  - Gas commonly produced: N_2
  - Gas bubble attaches to the sludge and increases buoyant force
  - Solutions
    - Increasing the return activated sludge withdrawal rate from the clarifier (less residence time of sludge in the clarifier)
    - Temporally decreasing the rate of flow of aeration liquor into the clarifier
    - Increasing the speed of the sludge collecting mechanism
    - Decreasing the SRT (prevent nitrification) or add an anoxic reactor (complete nitrification-denitrification)

BOD removal & nitrification – varieties of AS

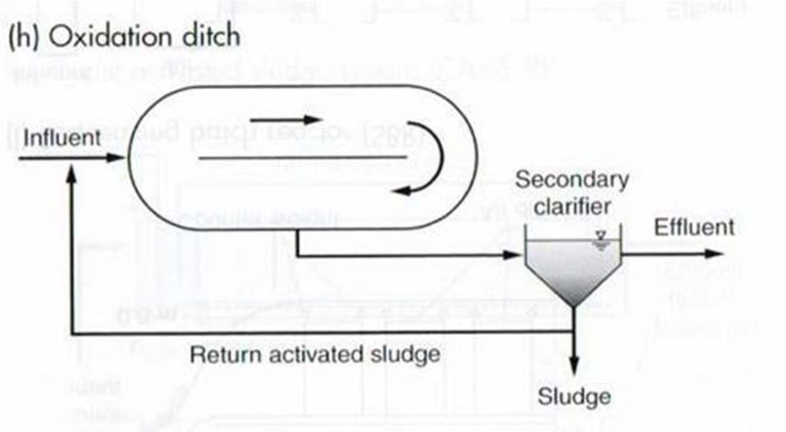


Step feed is a modification of the conventional plug flow process in which the settled wastewater is introduced at 3 to 4 feed points in the aeration tank to equalize the F/M ratio, thus lowering peak oxygen demand. Generally, three or more parallel channels are used. Flexibility of operation is one of the important features of this process because the apportionment of the wastewater feed can be changed to suit operating conditions. The step feed process has the capability of carrying a higher solids inventory, and thus, a higher SRT for the same volume as a conventional plug flow process.

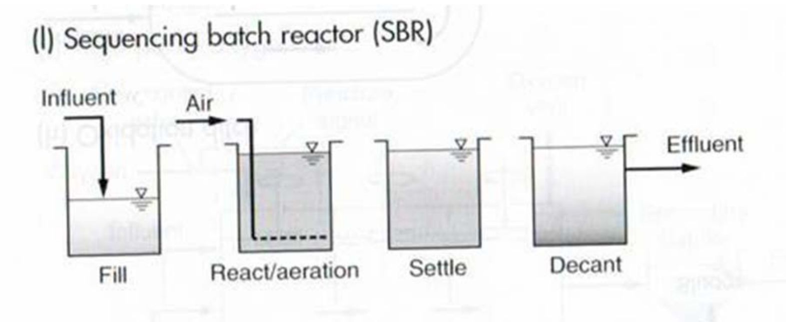


Contact stabilization uses two separate tanks or compartments for the treatment of the wastewater and stabilization of the activated sludge. The stabilized activated sludge is mixed with the influent (either raw or settled) wastewater in a contact zone. The contact zone retention time is relatively short (30 to 60 min), and the MLSS concentration in the contact zone is lower than that in the stabilization zone. Rapid removal of soluble BOD occurs in the contact zone and colloidal and particulate organics are captured in the activated sludge floc for degradation later in the stabilization zone. In the stabilization zone, return activated sludge is aerate and the retention time is in the order of 1 to 2 h to maintain a sufficient SRT for sludge stabilization. Because the MLSS concentration is so much higher in the stabilization zone, the process requires much less aeration volume than conventional activated sludge processes for the same SRT.

AS processes for BOD removal & nitrification

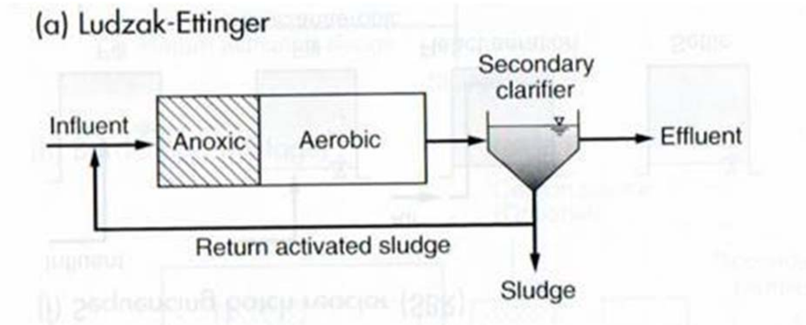


The oxidation ditch consists of a ring- or racetrack-shaped channel equipped with mechanical aeration and mixing devices. Screened and degritted wastewater enters the channel and is combined with the return activated sludge. The tank configuration and aeration and mixing devices promote unidirectional channel flow, so that the energy used for aeration is sufficient to provide mixing in a system with a relatively long HRT. As the wastewater leaves the aeration zone, the DO concentration decreases and denitrification may occur downstream from the aeration zone.

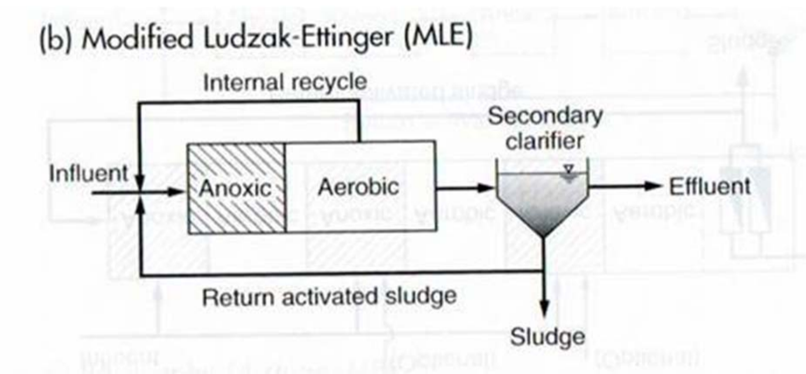


The SBR is a fill and draw type reactor system involving a single complete mix reactor in which all steps of the activated sludge process occur. For municipal wastewater treatment with continuous flow, at least 2 basins are used so that one basin is in the fill mode while the other goes through react, solids settling, and effluent withdrawal. An SBR goes through a number of cycles per day; a typical cycle may consist of 3-h fill, 2-h aeration, 0.5-h settle, and 0.5-h for withdrawal of supernatant. An idle step may also be included to provide flexibility at high flows. Mixed liquor remains in the reactor during all cycles, thereby eliminating the need for separate secondary sedimentation tanks.

Suspended growth processes for N removal

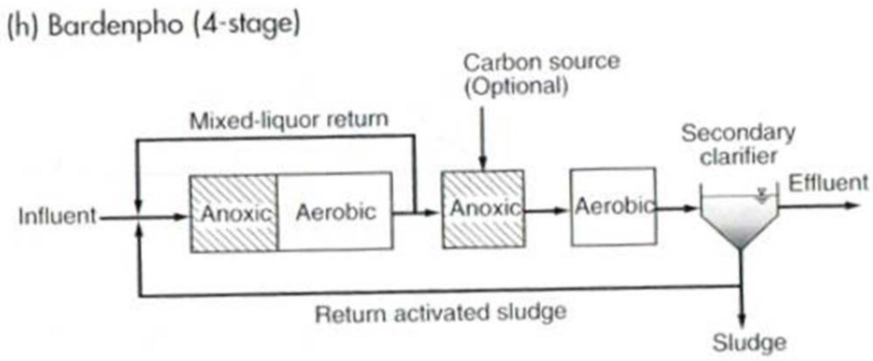


The first concept of a preanoxic BNR was an anoxic-aerobic operating sequence by Ludzak and Ettinger (1962). The influent wastewater was fed to an anoxic zone, which was followed by an aerobic zone. The process relies on the nitrate formed in the aerobic zone being returned via the return activated sludge (RAS) to the anoxic zone. Because the only nitrate fed to the anoxic zone is that in the RAS, denitrification is limited greatly by the RAS recycle ratio.



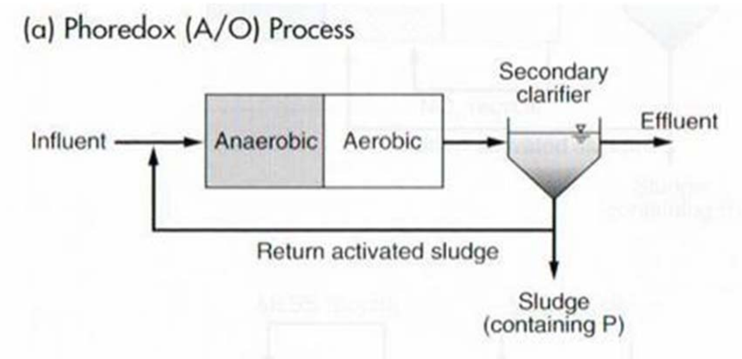
One of the most commonly used BNR processes is the MLE process. Barnard (1973) improved on the original LE design by providing the internal recycle to feed more nitrate to the anoxic zone directly from the aerobic zone. Both the denitrification rate and overall nitrogen removal efficiency are increased. The internal recycle flow ratio (recycle flowrate divided by influent flowrate) typically ranges from 2 to 4. The MLE process is very adaptable to existing activated sludge facilities and can easily meet a common effluent standard of less than 10 mg/L total nitrogen.

Suspended growth processes for N removal

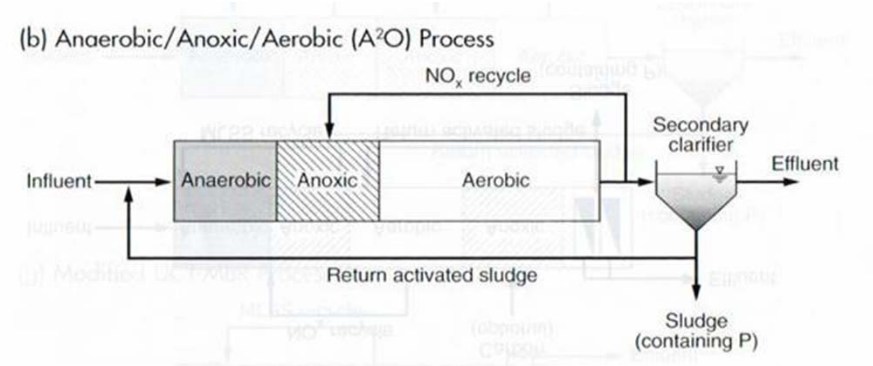


Both preanoxic and postanoxic denitrification are incorporated in the Bardenpho process, which was developed and applied at full-scale facilities in South Africa in the mid-1970s, before making its way to the U.S. in 1978. In the postanoxic zone, the NO_3-N concentration leaving the aeration zone is typically reduced from about 5 to 7 mg/L to less than 3 mg/L. Barnard (1974) found that biological phosphorus removal occurred as well as nitrogen removal, hence the basis for the process name (the name comes from the first three letters of the inventor's name, Barnard, and from denitirification, and phosphorus). Carbon can be added to the postanoxic zone to provide lower effluent NO_3-N concentrations and to reduce the postanoxic tank volume. Effluent NO_3-N concentrations of less than 1.0 or 2.0 mg/L are possible.

Suspended growth processes for P removal

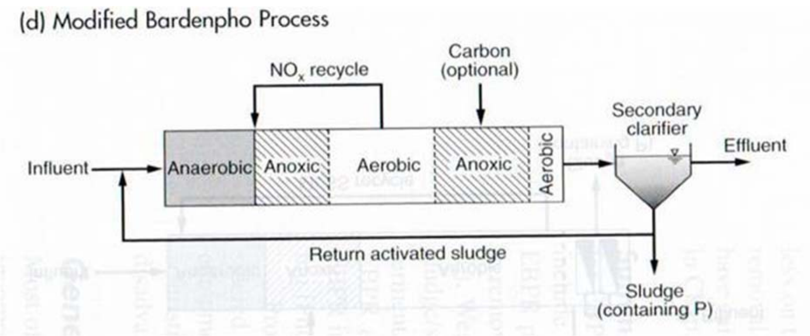


The basic process configuration for biological P removal consists of an anaerobic zone followed by an aerobic zone. Barnard (1974) was the first to clarify the need for anaerobic contacting between activated sludge and influent wastewater before aerobic degradation to accomplish enhanced biological P removal.



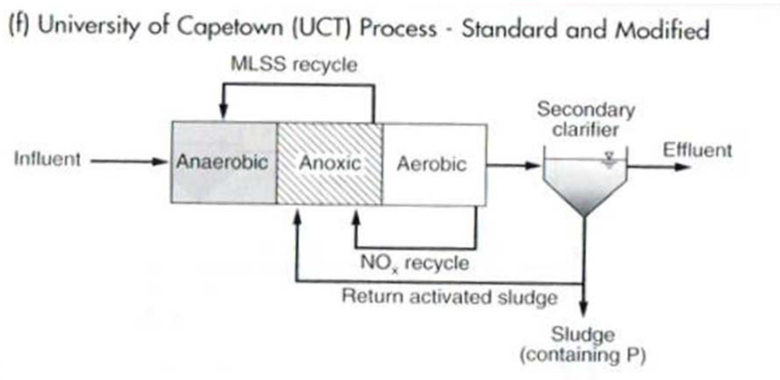
The A^2O process has an anoxic zone located between the anaerobic and aerobic zones and is used for enhanced biological P removal systems that have nitrification. Nitrate is recycled from the aerobic zone to the anoxic zone for denitification. Use of the anoxic zone minimizes the amount of nitrate fed to the anaerobic zone in the return activated sludge.

Suspended growth processes for P removal



The Bardenpho process can be modified for combined N and P removal. The 5-stage system provides anaerobic, anoxic, and aerobic stages for P, N, and C removal. Mixed liquor from the first aerobic zone is recycled to the preanoxic zone. A second anoxic stage is provided for additional denitrification using nitrate produced in the first aerobic zone as the electron acceptor, and the endogenous organic carbon as the electron donor. An option is to add an exogenous carbon source to the second anoxic zone so that it has a shorter retention time and can produced lower effluent NO_3-N concentration. The final aerobic stage is used to strip residual nitrogen gas from solution and to raise the DO concentration to minimize P release in the secondary clarifier.

Suspended growth processes for P removal

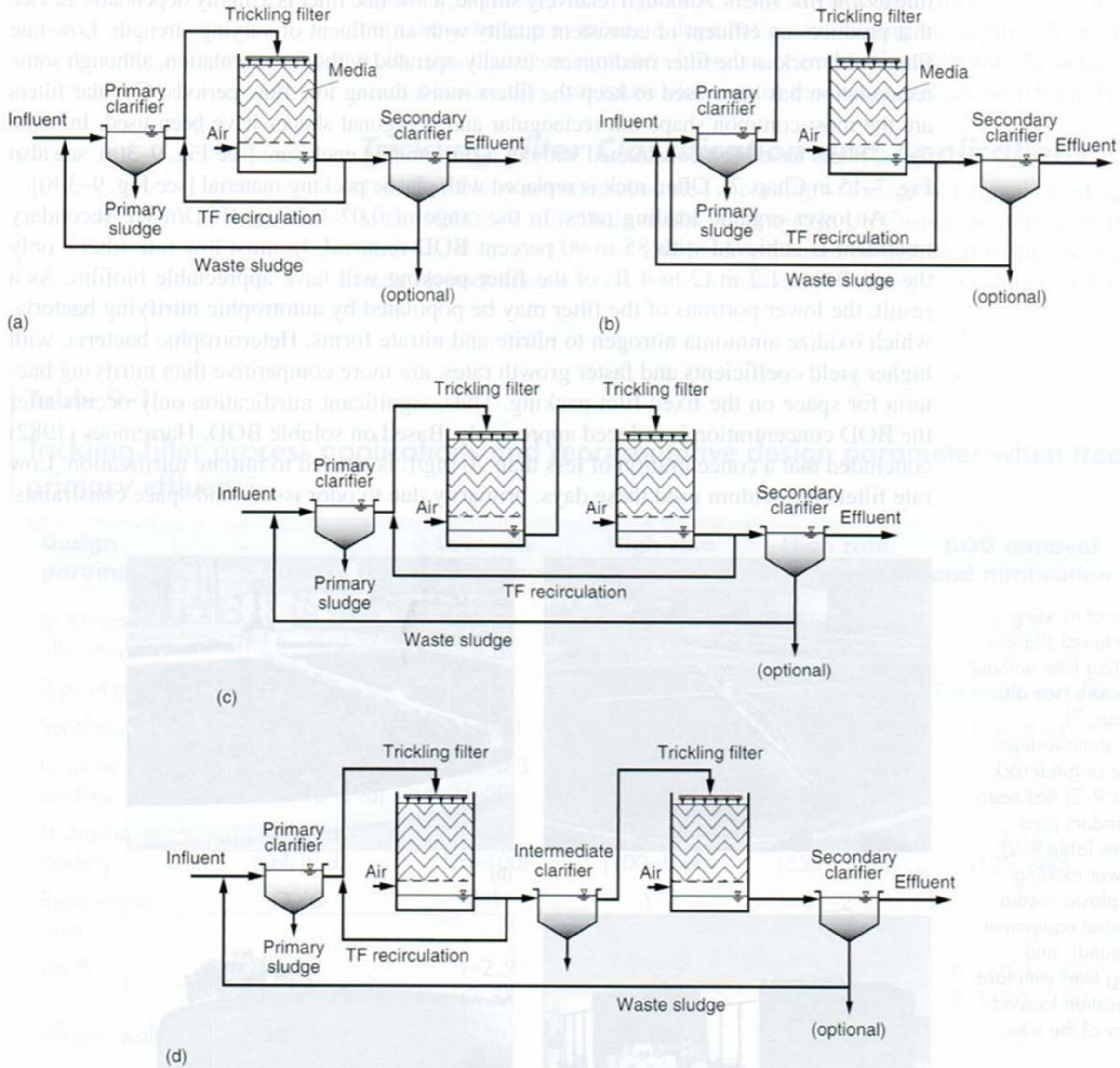


The UCT process was developed at the Univ. of Cape Town (South Africa) to minimize the effect of nitrate entering the anaerobic contact zone in enhanced biological P removal (EBPR) processes treating weak wastewaters. The UCT process has three recycle streams instead of two as in the A^2O process. The return activated sludge from the secondary clarifier is directed to the anoxic zone instead of the anaerobic zone. Similar to the A^2O process, internal recycle feed NO_x to the anoxic zone from the aerobic zone. The anaerobic zone receives mixed liquor from the anoxic zone instead of the return activated sludge flow so that the introduction of nitrate to the anaerobic stage is eliminated. Thus, more of the influent rbCOD is available for the PAOs in the anaerobic zone which can improve the EBPR efficiency.

Attached growth processes

- **General features**
  1. Growth of the biomass on inert media to form biofilm
  2. Removal of excess solids by sedimentation after solids sloughing off the biofilm or by backwashing the media
  3. Need to provide oxygen by
     1) Air movement through the void volume (e.g., in trickling filters)
     2) Air sparging into fixed or moving submerged media
     3) Oxygenation of recycle flow in a fluidized bed reactor
  4. Need to provide distribution and contact of the influent flow with the media surface area
  5. Need for an underdrain or other methods of collecting the treated effluent

Trickling filter

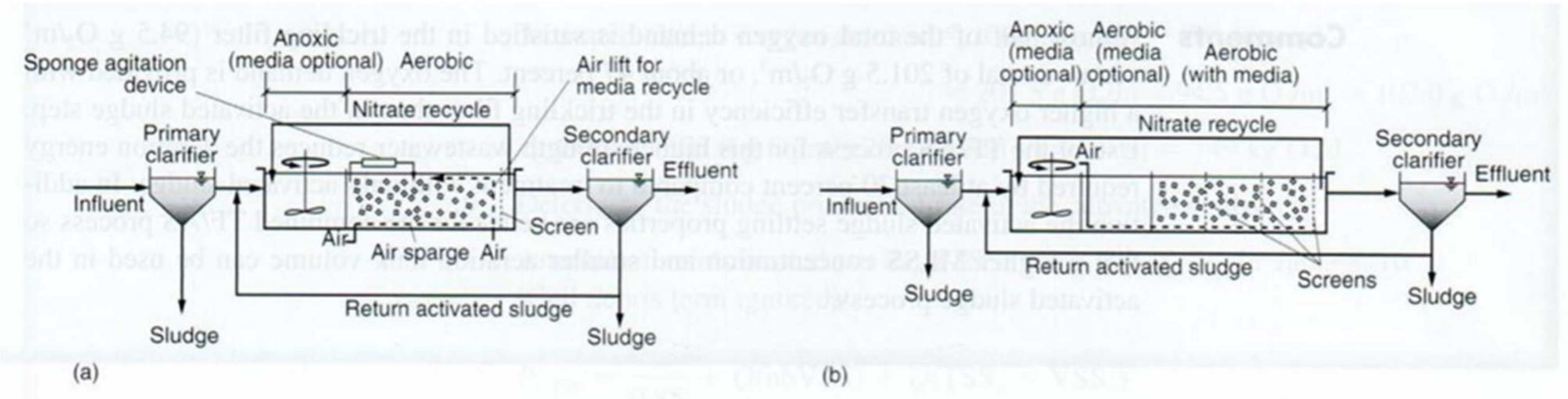


Trickling filters – adv. & disadv.

Advantages	Disadvantages
1. Less energy required	1. Generally poorer effluent quality than activated sludge process
2. Simpler operation	2. High sensitivity to low temperature
3. NO problems of bulking sludge in secondary clarifiers	3. Odor production
4. Better sludge thickening properties	4. Uncontrolled solids sloughing events
5. Better recovery from shock toxic loads	

Integrated fixed film AS process

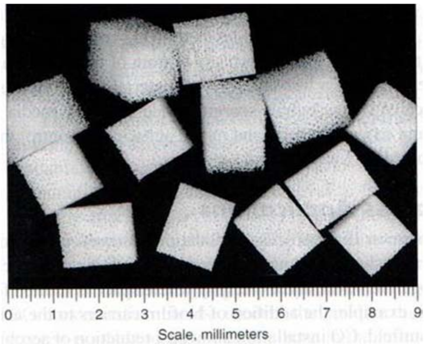
- **Activated sludge system in which a material to support attached biomass growth is added**
- **Higher biomass concentration achievable in the aeration tank**
  - Can use higher volumetric OLR
  - Provide conditions for nitrification



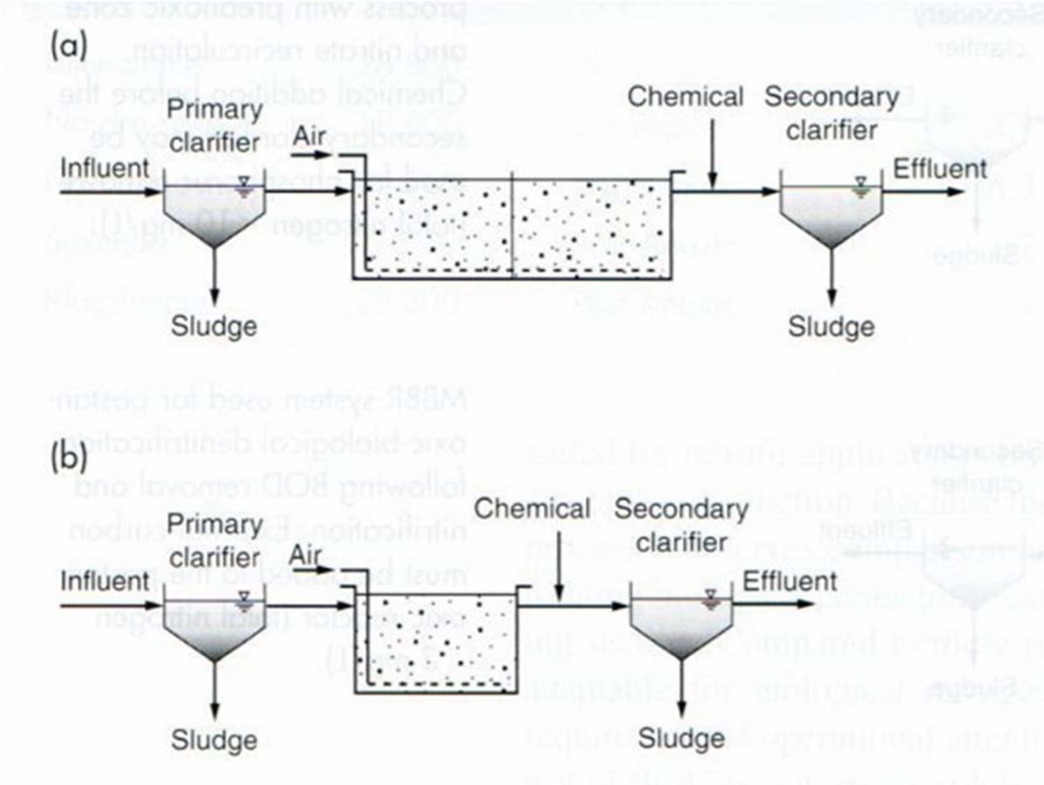
Moving bed biofilm reactor

- **Similar to the IFAS process, but no sludge return**
  - Media fill volume is higher
  - TSS concentration in the flow to the secondary clarifier much smaller

- **Processes for BOD removal:**

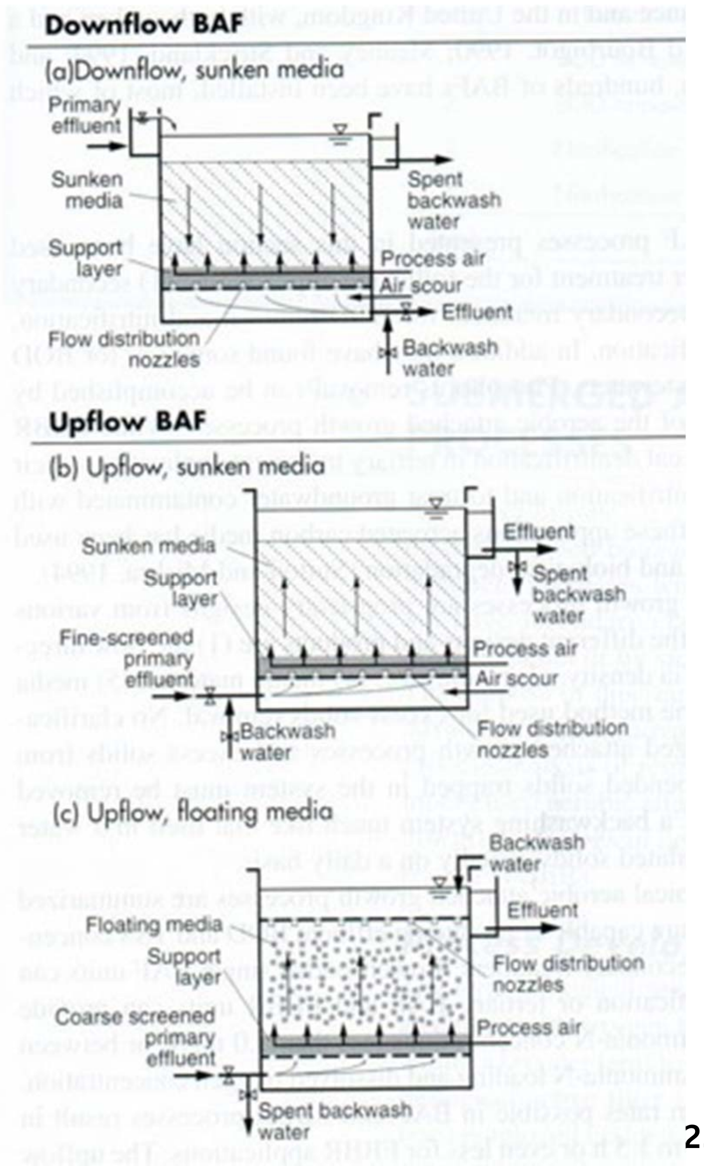


Media used for IFAS or MBBR processes



Biological aerated filters (BAFs)

- **Upflow or downflow**
- **Sunken or floating media**
  - Floating media for upflow only
  - Sunken media: Use a bed of heavy media (expanded clay or shale, specific gravity of about 1.6)
  - Floating media: use media lighter than water



Fluidized bed bioreactor

- Wastewater is fed upward at a relatively high velocity to expand the media bed
- Use sand or activated carbon as media
- Usually provide oxygen in the recycle flow