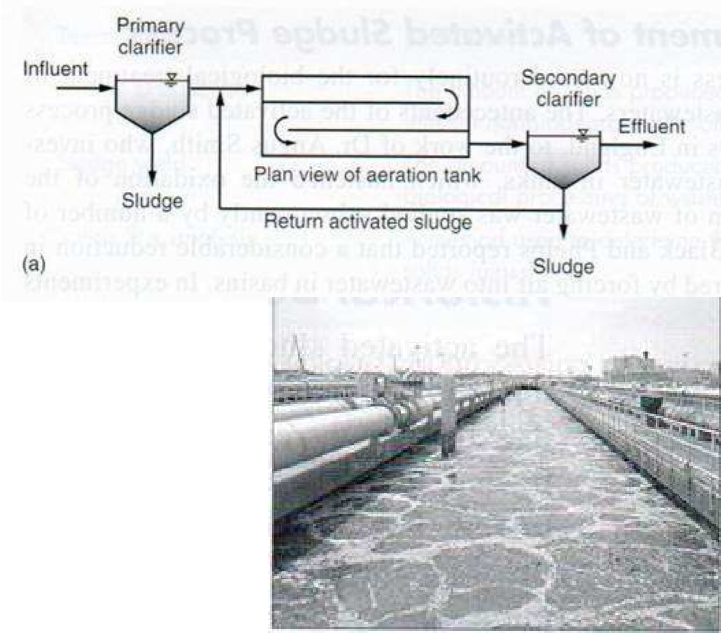
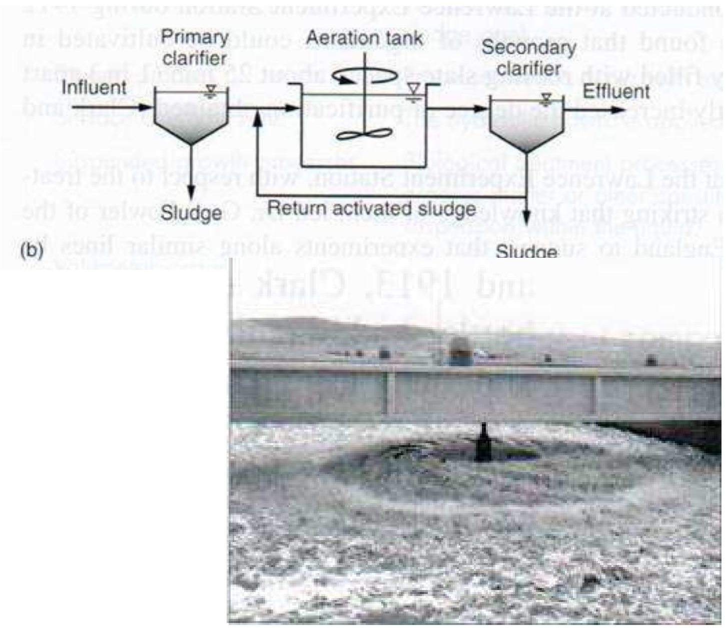
Practical applications of biological wastewater treatment

Activated sludge – different configurations (1)

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

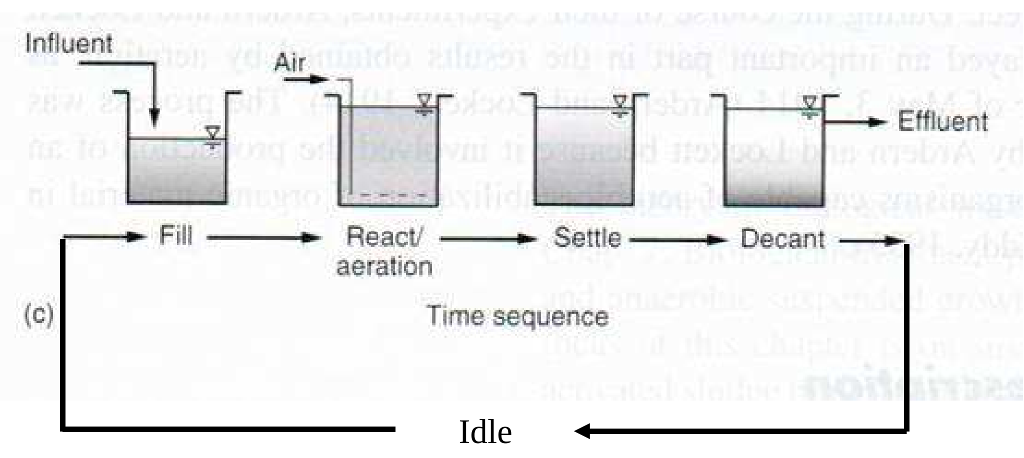




- **Complete-mix process configuration**
  - Dilution in the reactor → much less toxic effects
  - Single-stage, complete-mix activated sludge (CMAS) process common in 1970s and early 1980s

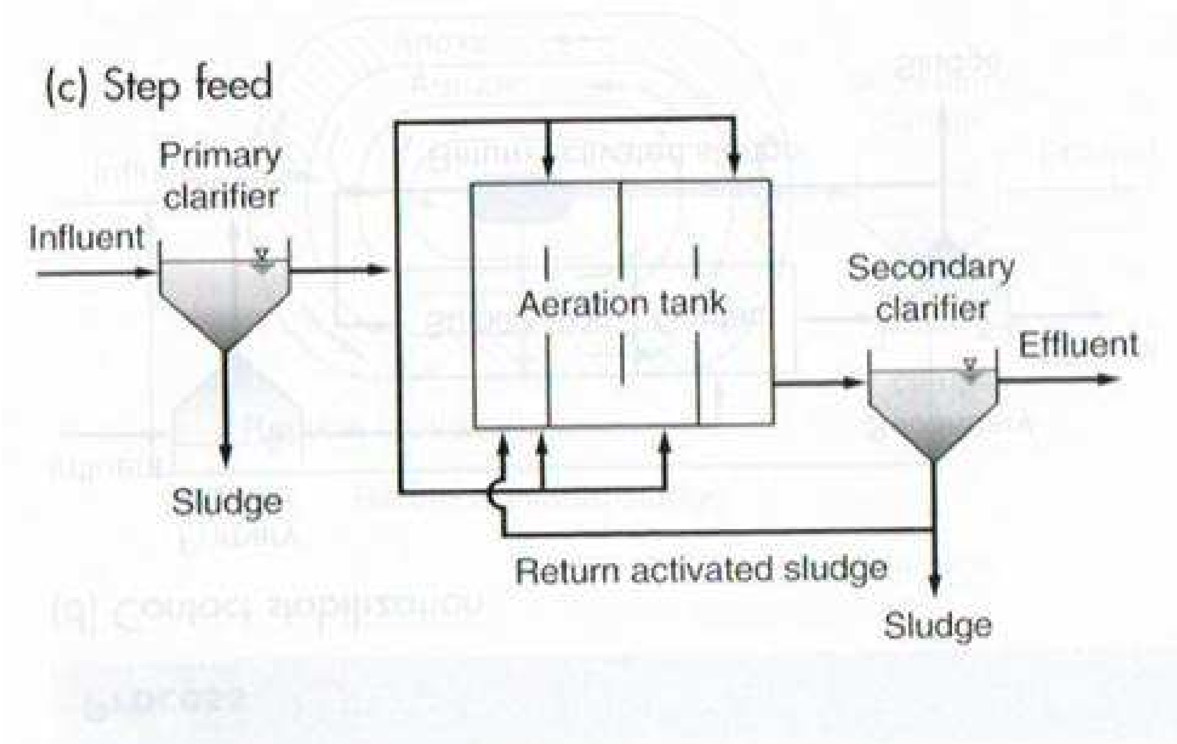
Activated sludge – different configurations (2)

- **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

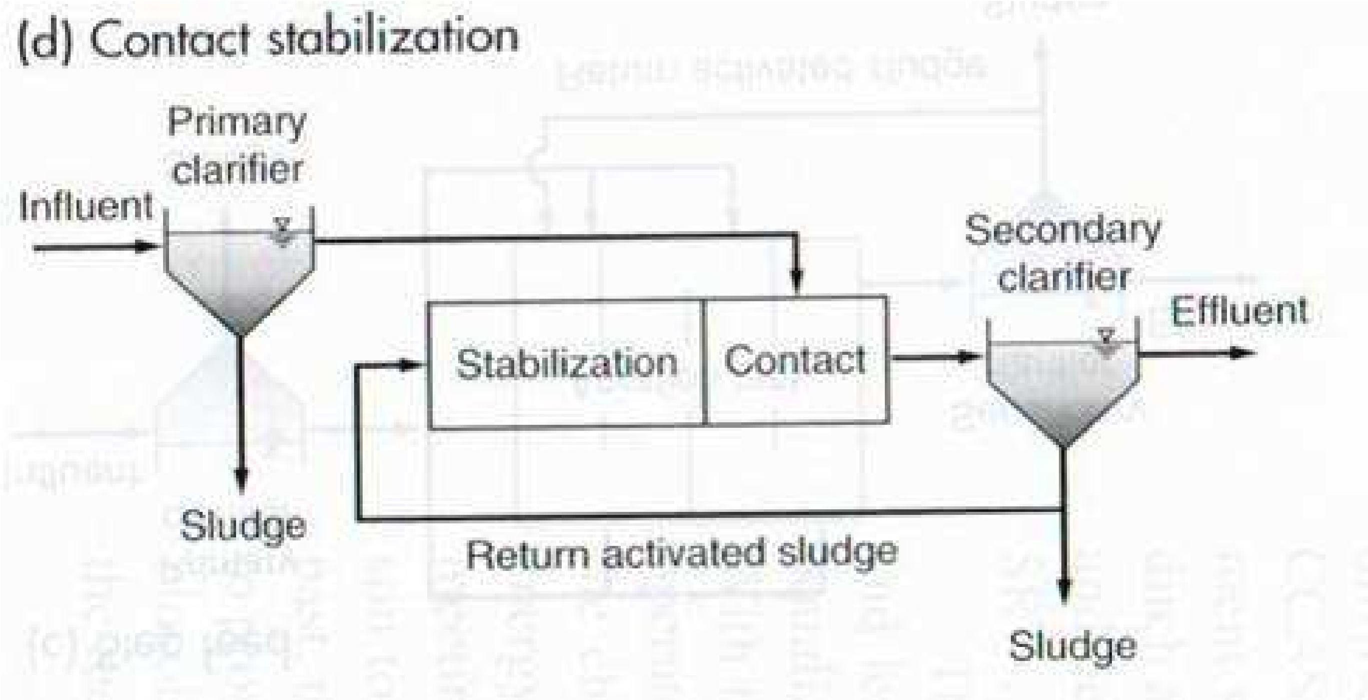


Other modification of activated sludge

- Various types for BOD removal and nitrification:
  - **Step feed**
  - **Contact stabilization**
  - **Oxidation ditch**
  - …

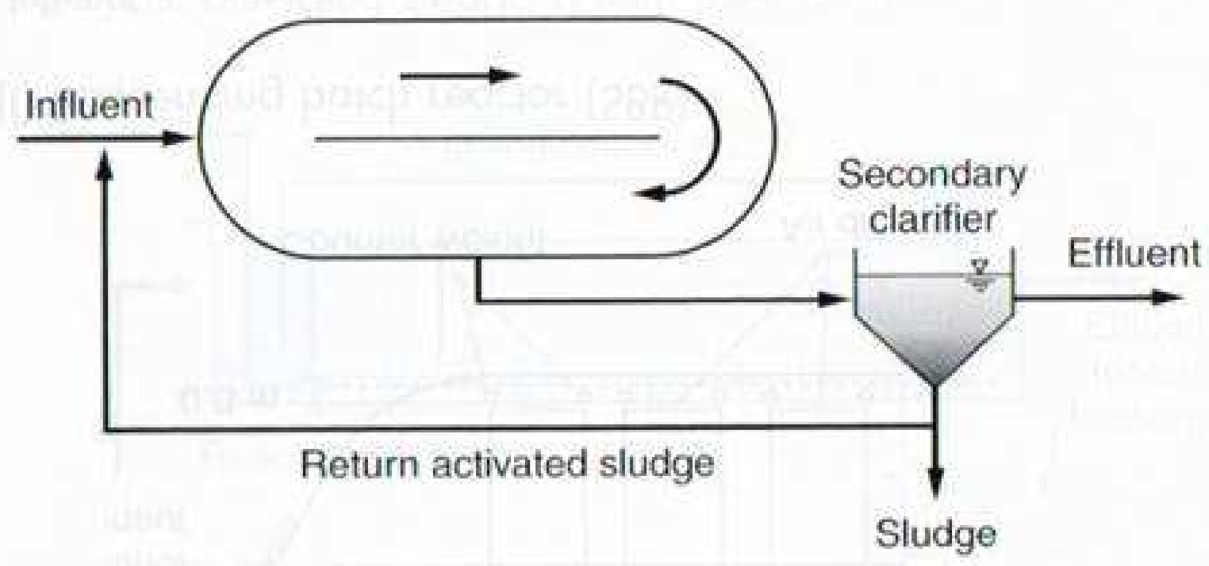


Step feed is a modification of the conventional plug flow process in which the settled wastewater is introduced at 3 to 4 feed points in the aeration tank to equalize the F/M ratio, thus lowering peak oxygen demand. Generally, three or more parallel channels are used. Flexibility of operation is one 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.

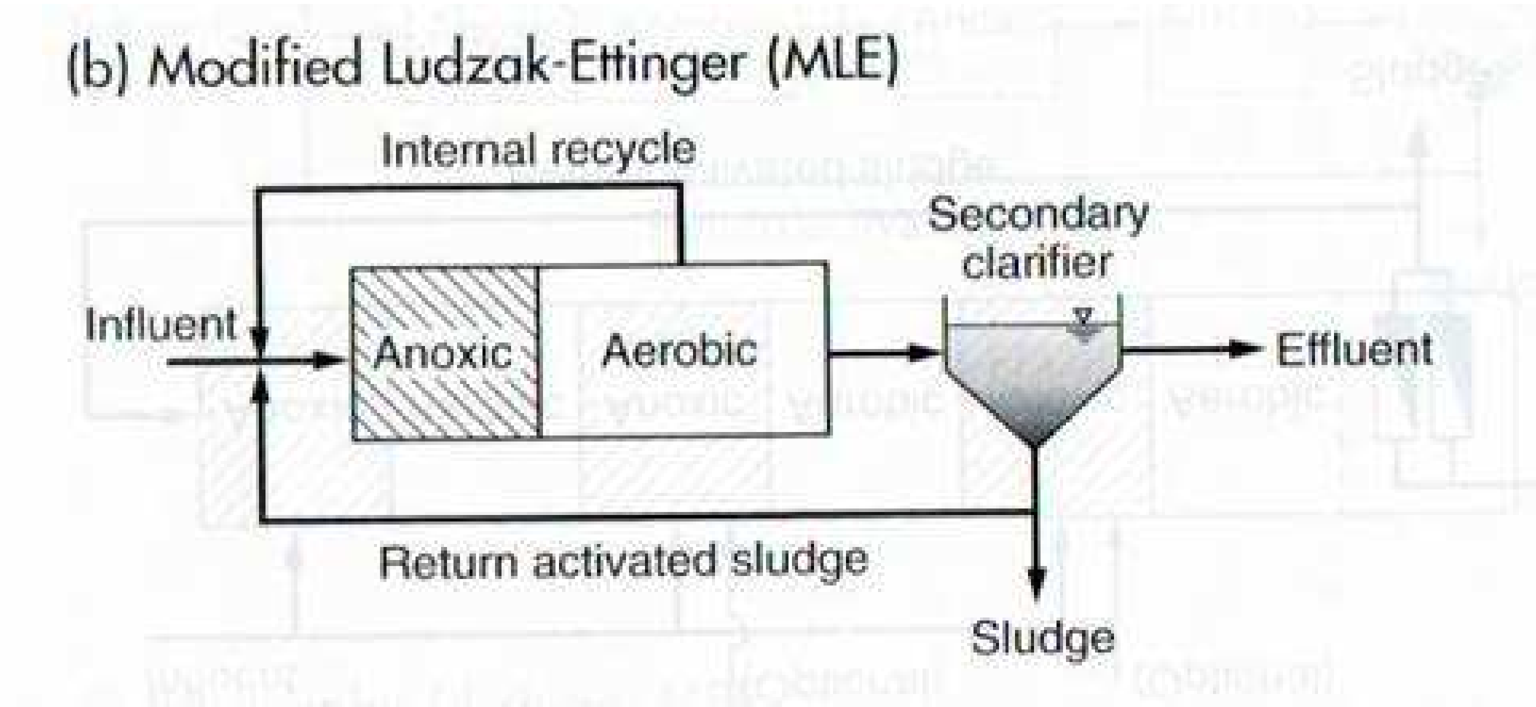
(h) Oxidation ditch



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.

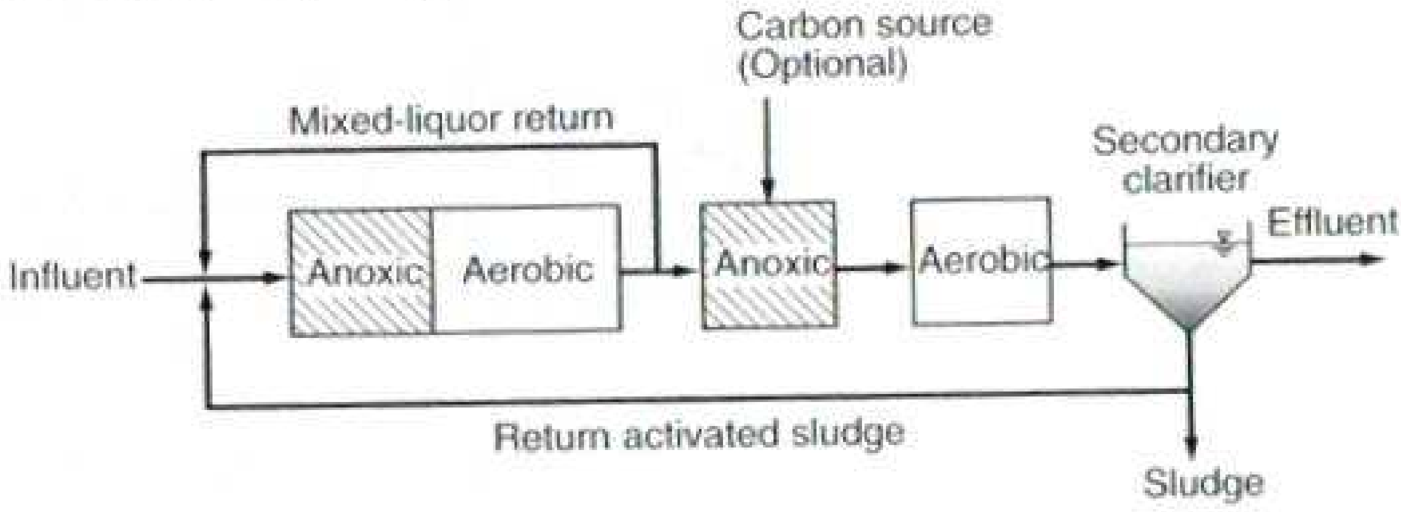
Suspended growth process for N/P removal

- Nitrogen (N) removal
  - **Modified Ludzack-Ettinger (MLE)**
  - **4-stage Bardenpho**
  - ….
- Phosphorus (P) removal
  - **A/O**
  - ….
- N & P removal
  - **A^2O**
  - **Modified Bardenpho (5-stage)**
  - **University of Capetown**
  - …

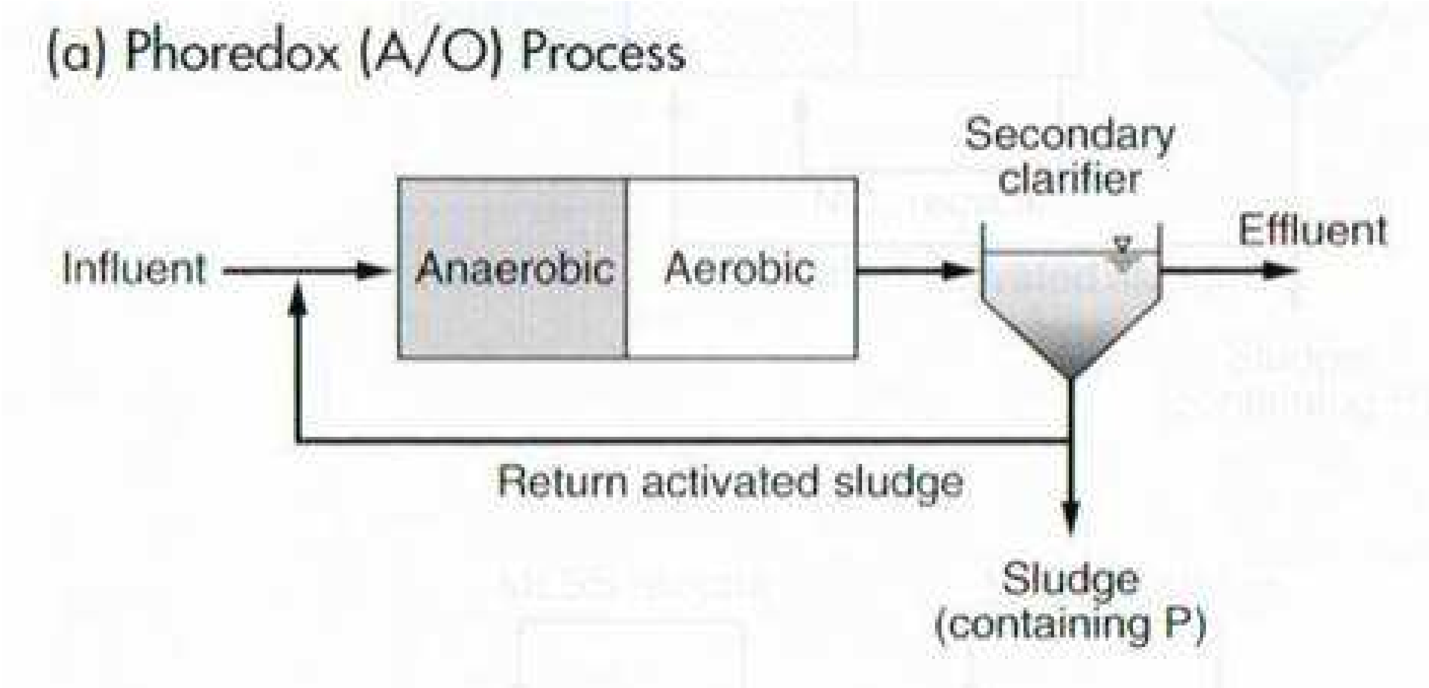


One of the most commonly used BNR processes is the MLE process. Barnard (1973) improved on the original LE (Ludzack-Ettinger) design by providing the internal recycle to feed more nitrate to the anoxic zone directly from the aerobic zone. Both the denitrification rate and overall nitrogen removal efficiency 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.

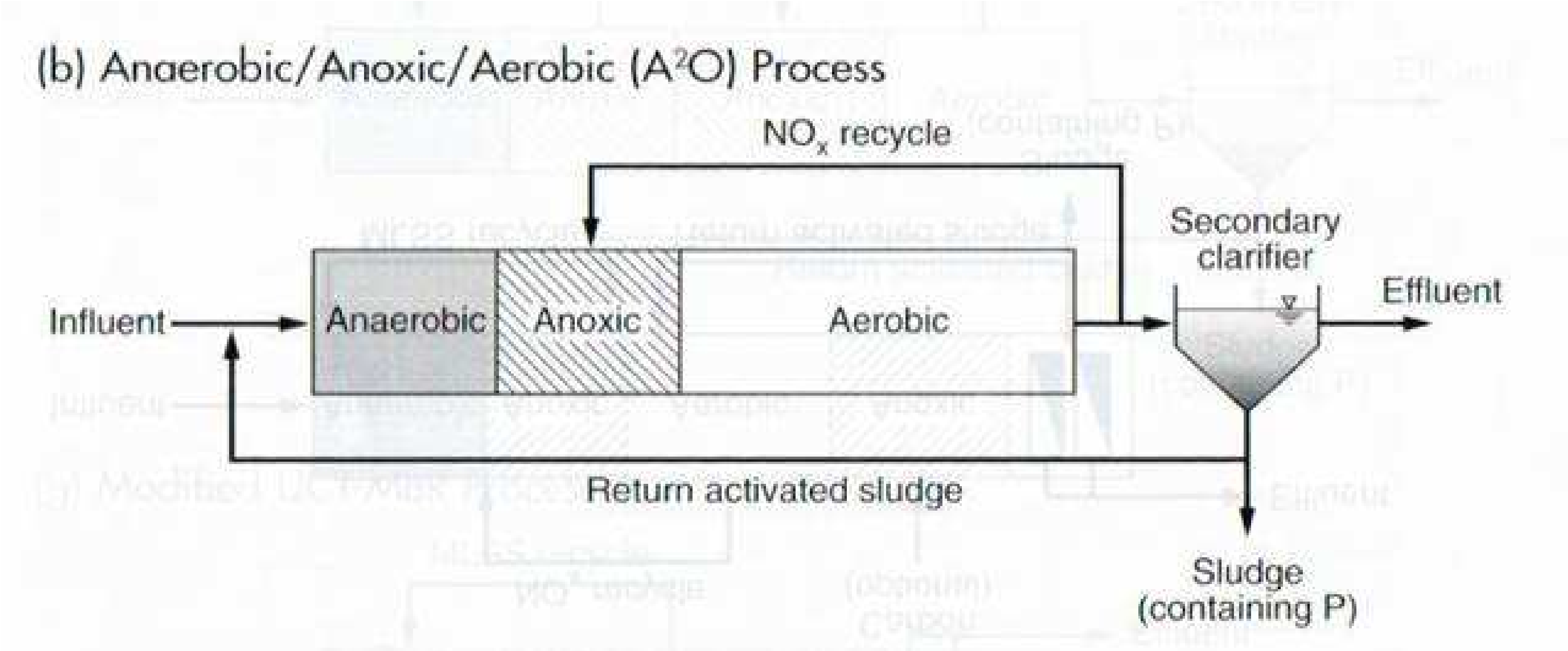
(h) Bardenpho (4-stage)



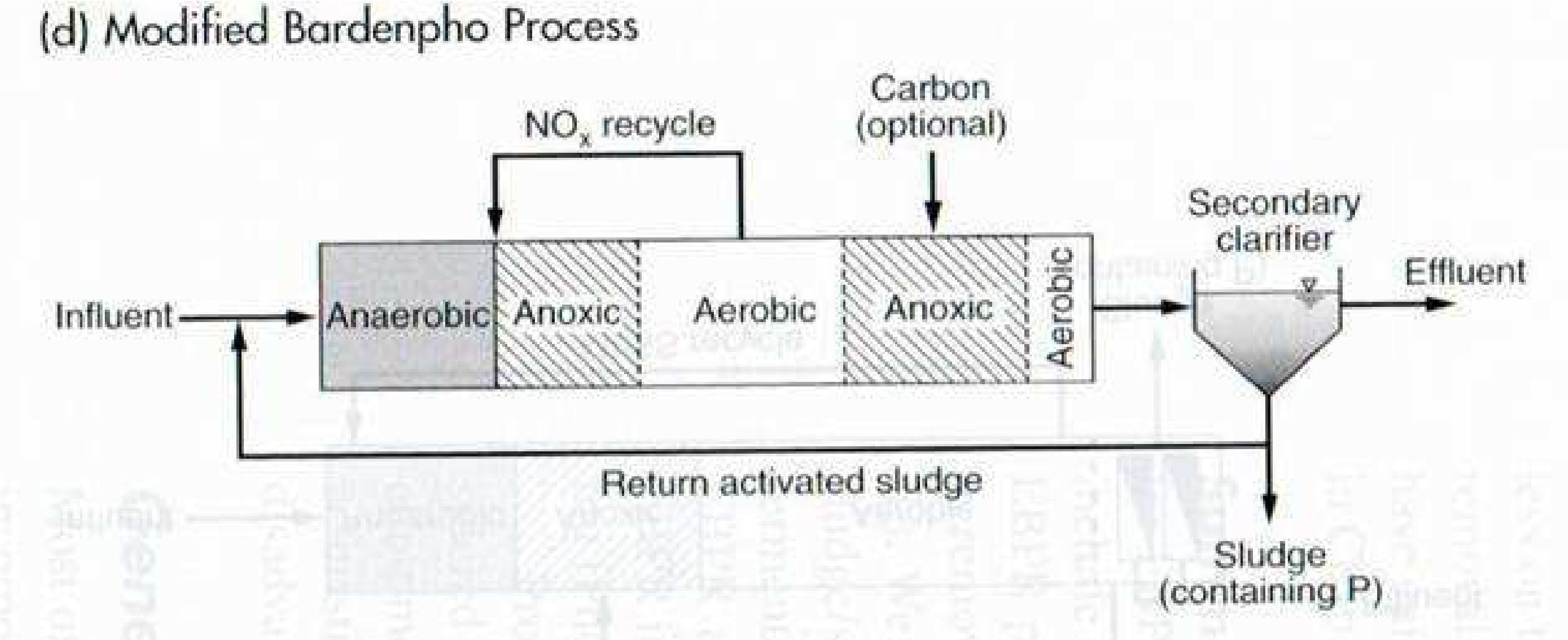
Both preanoxic and postanoxic denitrification are incorporated in the Bardenpho process, which was developed and applied at full-scale facilities in South Africa in the mid-1970s, before making its way to the U.S. in 1978. In the postanoxic zone, the NO_3-N concentration leaving the aeration zone is 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.



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.

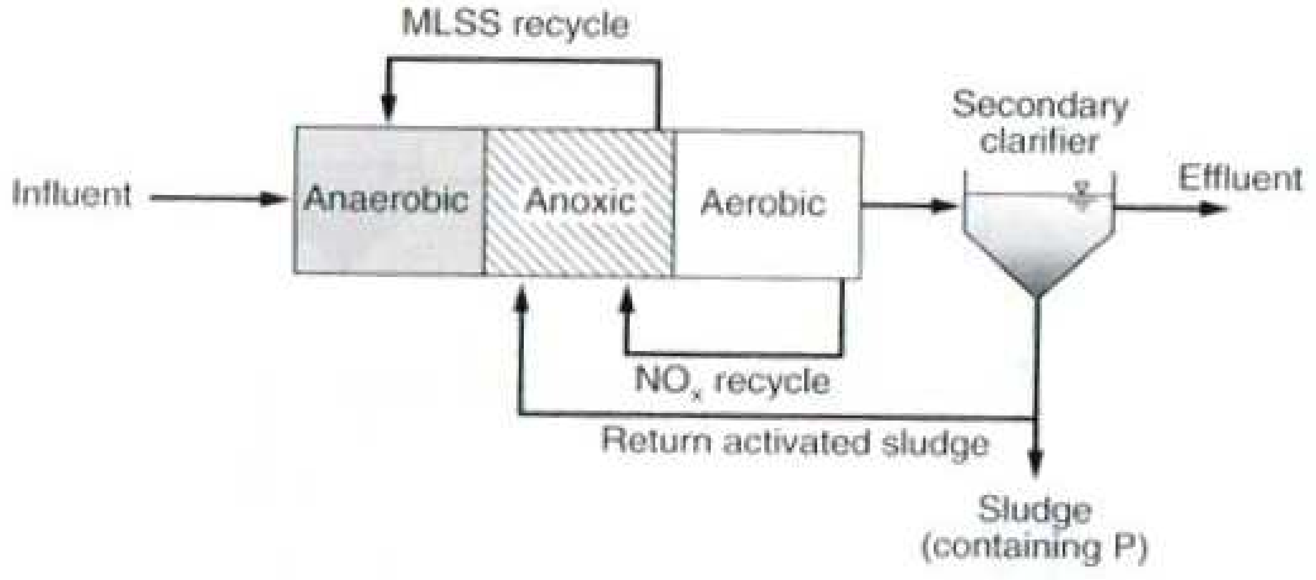


The A^2O process has an anoxic zone located between the anaerobic and aerobic zones and is used for enhanced biological P removal systems that have nitrification. Nitrate is recycled from the aerobic zone to the anoxic zone for denitification. Use of the anoxic zone minimizes the amount of nitrate fed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



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.

(f) University of Capetown (UCT) Process - Standard and Modified

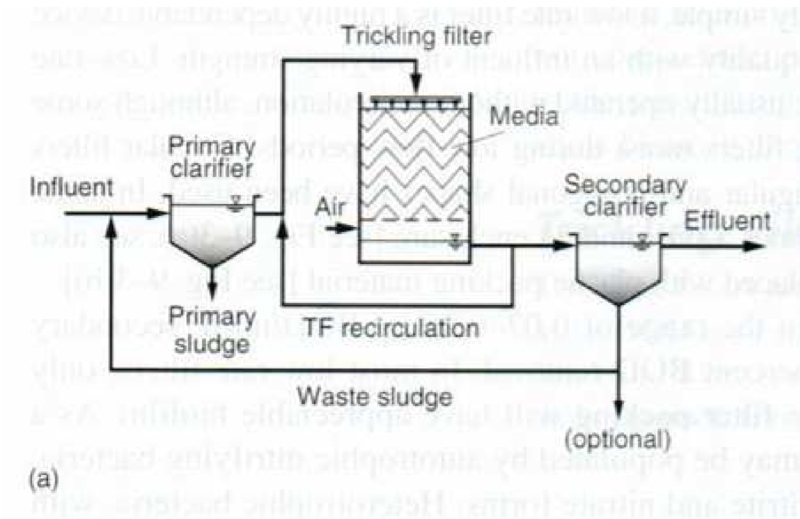


The UCT process was developed at the Univ. of Cape Town (South Africa) to minimize the effect of nitrate entering the anaerobic contact zone in enhanced biological P removal (EBPR) processes treating weak wastewaters. The UCT process has three recycle streams instead of two as in the A^2O process. The 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 or combined processes

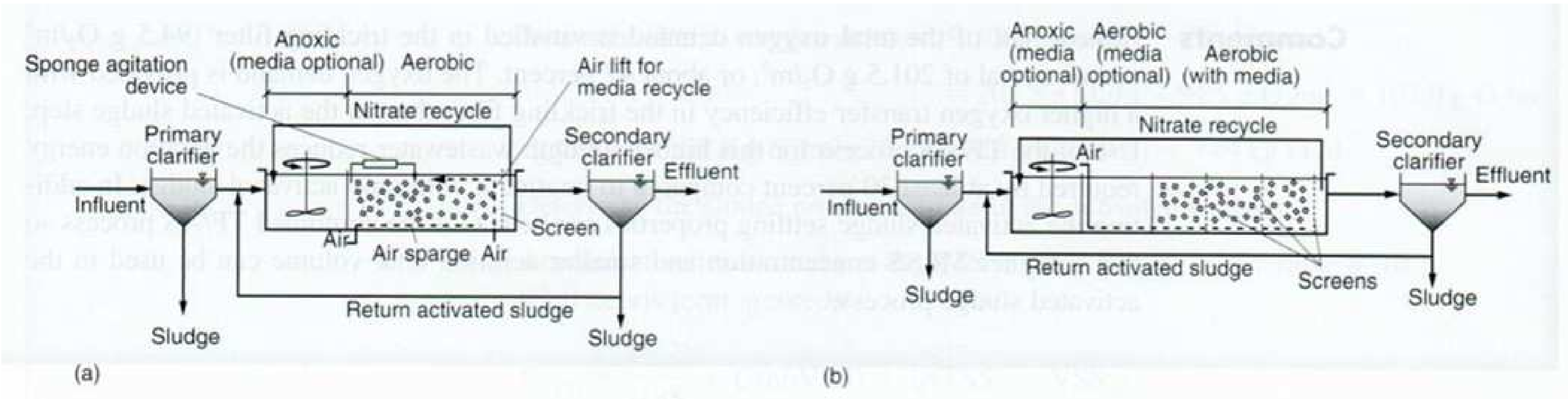
- Processes relies primarily on attached growth or suspended growth processes with an addition of floating media to support attached growth
  - Trickling filter
  - Rotating biological contactor
  - Integrated fixed activated sludge
  - Moving bed biofilm bioreactor
  - Biological aerated filter
  - Fluidized bed bioreactor
  - …

Trickling filter & rotating biological contactor



Integrated fixed film AS (IFAS) process

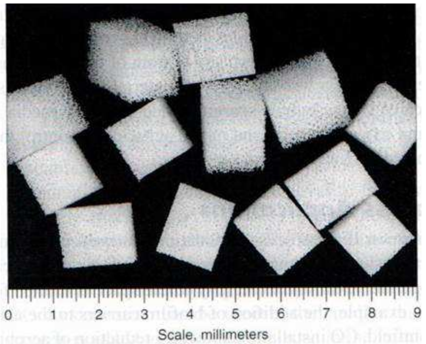
- **Activated sludge system in which a material to support attached biomass growth is added**
- **Higher biomass concentration achievable in the aeration tank**
  - Can use higher volumetric OLR
  - Provide conditions for nitrification



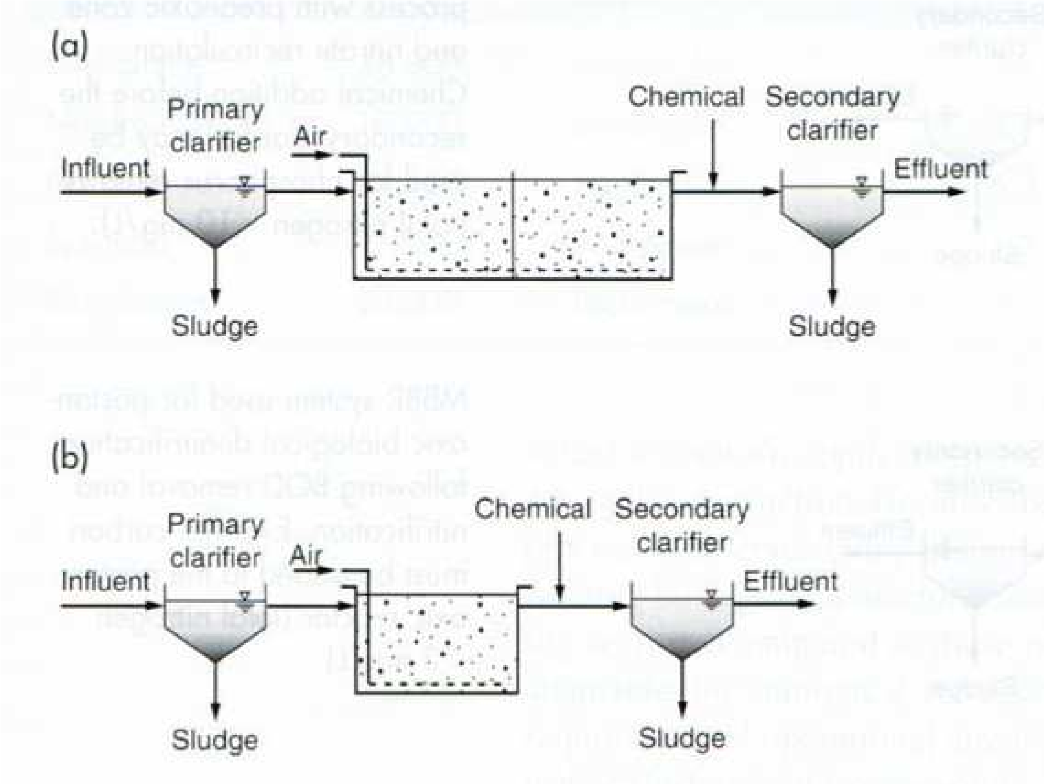
Moving bed biofilm reactor (MBBR)

- **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:**

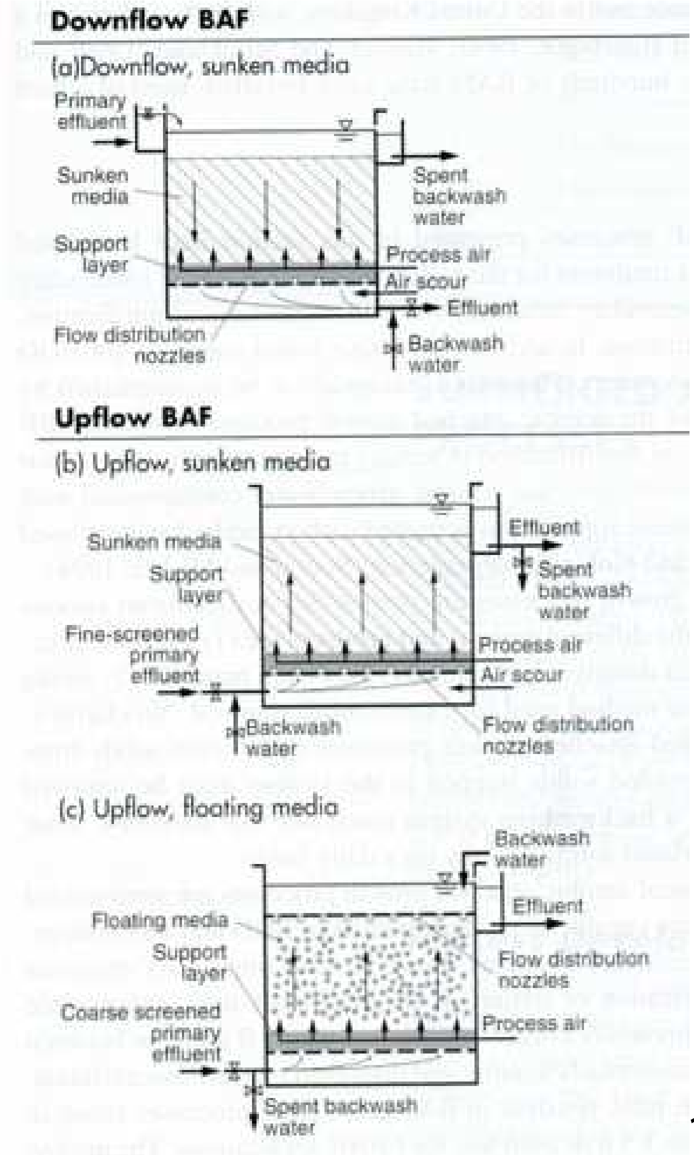


Media used for IFAS or MBBR processes



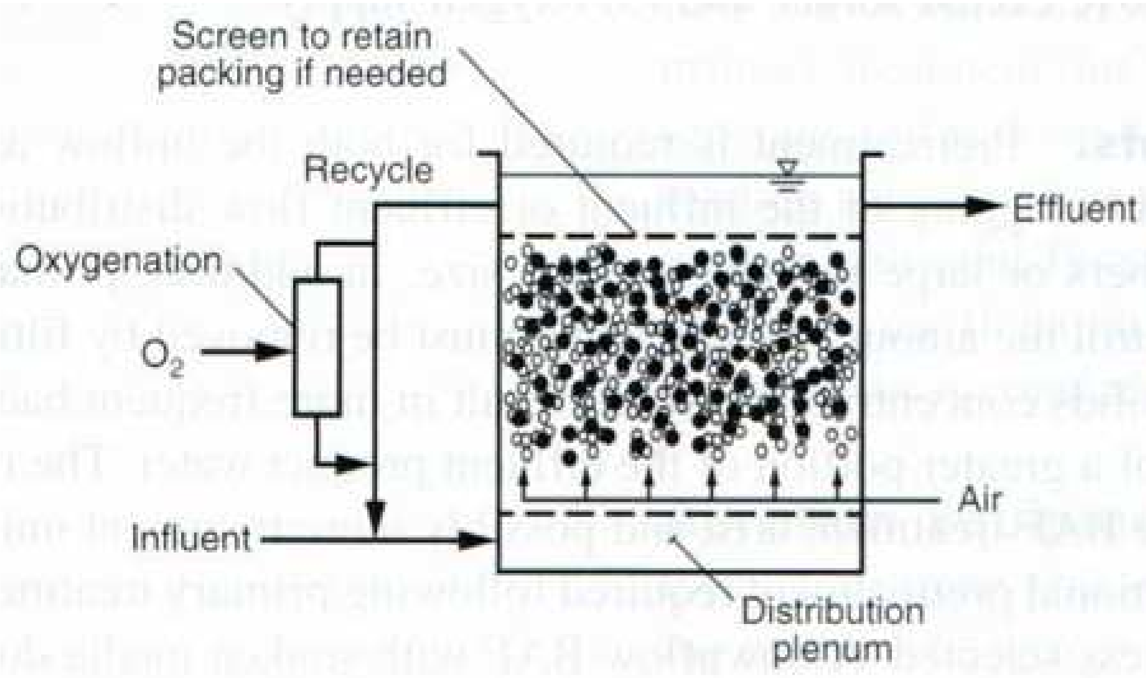
Biological aerated filters (BAFs)

- **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**



Emerging technologies of biological wastewater treatment

Membrane BioReactor (MBR)

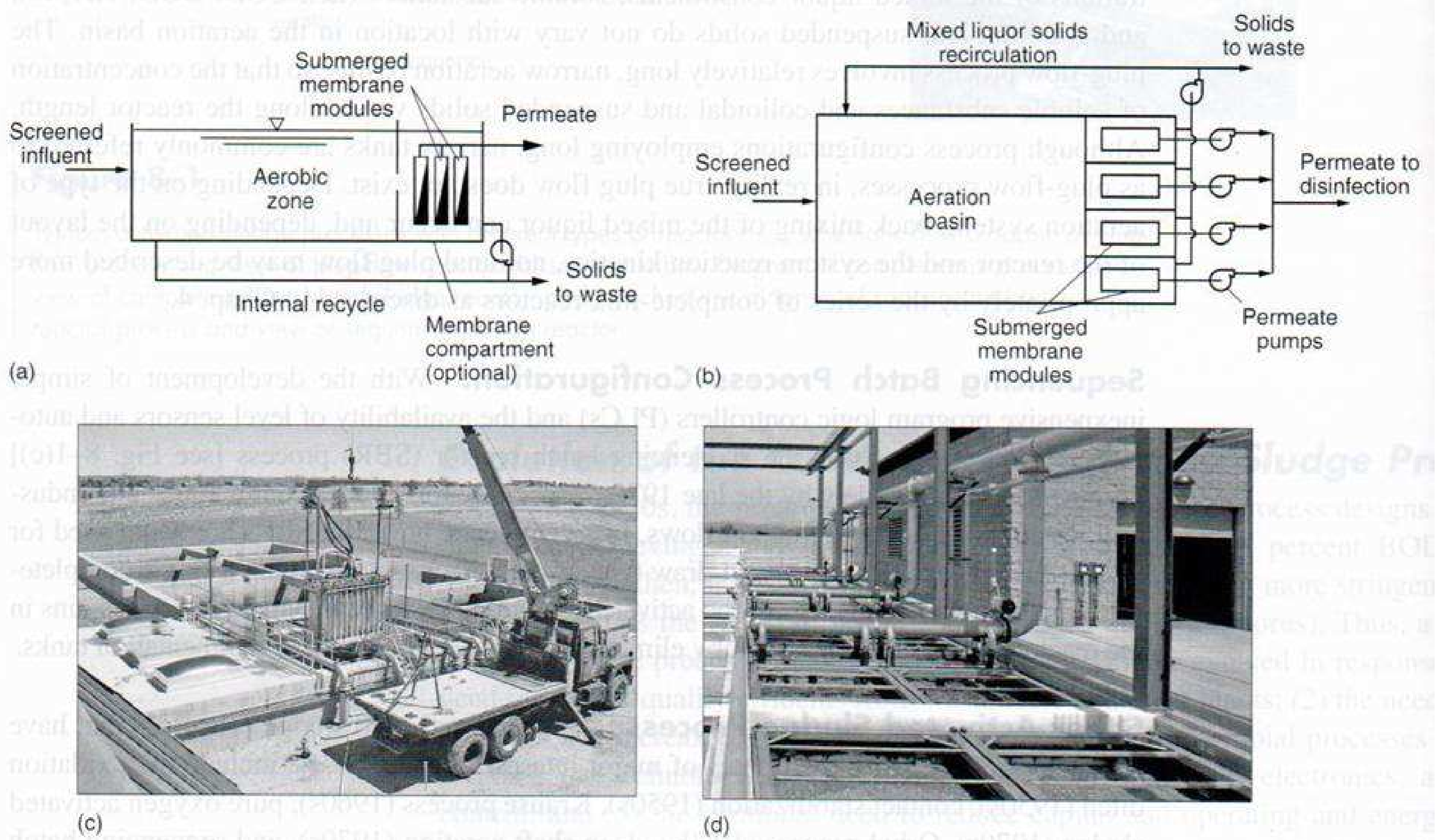


Figure 8–2

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: Concept & Performance

- Use membrane for solid/liquid separation
- Microfiltration or ultrafiltration membrane immersed directly into the reactor
- Effect: secondary treatment (aeration tank + clarifier) + tertiary treatment (granular media filtration)
- High removal efficiencies of BOD, SS, bacteria, and nutrients
- Membrane fouling a major concern: became feasible with advances in membrane manufacturing & configuration technique

MBR: Advantages & Disadvantages

- **Advantages**
  - 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

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

Aerobic granular sludge

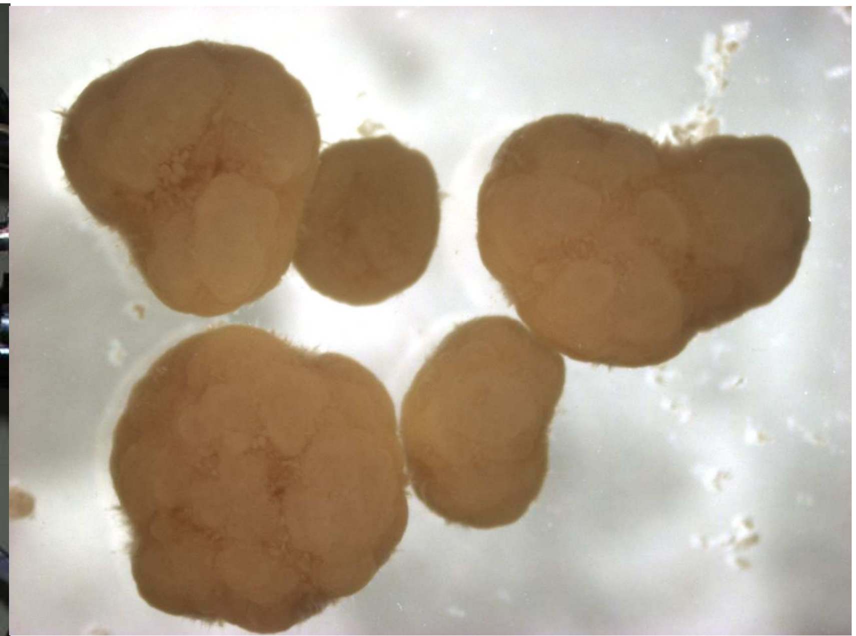
- Basic concept
  - Grow and utilize microbial **"granules"**, which are compact and dense aggregates, instead of microbial "flocs" used in conventional activated sludge

Parameter	Activated sludge	Aerobic granular sludge
Shape and average size	Irregular; Small, ~<0.2 mm	Large mm-sized distinct particles with well-defined spherical shape; >0.2 mm
Specific gravity	0.997-1.01	1.010-1.017
Settling velocity	Lower settling velocities ~<10 m/h	Higher settling velocities >10 m/h
Microenvironment within the particle	Minimum possibilities for anaerobic zones	Distinct layers or microenvironments i.e., aerobic, anaerobic and anoxic zones

Nancharaiah & Reddy Bioresour. Technol., 2018

Aerobic granular sludge: Operational scheme

- Usually employed in sequential batch reactor (SBR) settings
- Operation requirements to accomplish granulation
  - **Feast-famine feeding regimes**: expose microorganisms to alternating condition of presence/absence of organic matter → granule formers are competitive at this condition (can store organic matter in cells during the famine period)
  - **Hydrodynamic shear force**: high shear forces favor the granule formation and improve the physical granule integrity
  - **Short settling time**: selectively collect granules while flushing out flocs



Aerobic granules

SBR with aerobic granules

Aerobic granular sludge: Advantages

- **Stability**
  - Good performance with shock and fluctuating organic loading
- **Low energy requirement**
  - High aeration efficiency
  - Neither sludge return nor nitrate recycle streams required
- **Low space requirement**
  - High organic loading rate (OLR) due to high biomass concentration
  - Clarifier not required
- **Simultaneous removal of BOD & N/P**
  - Layer of microenvironments formed within the granule

  → simultaneous nitrification-denitrification: aerobic/anoxic

  → enhanced biological phosphorus removal (EBPR): aerobic/anaerobic

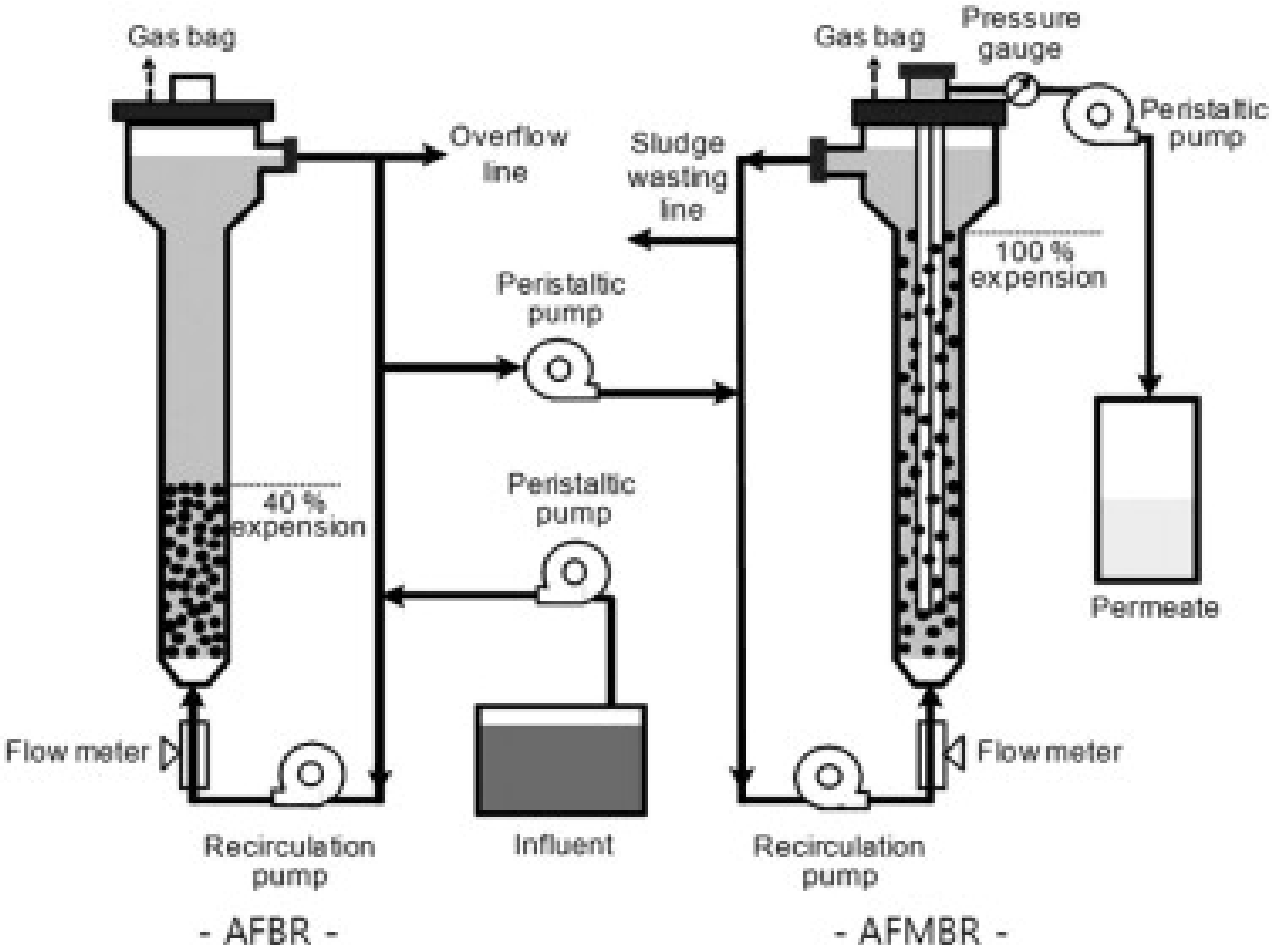
Aerobic granular sludge: Current status

- Adapted for industrial applications from mid 2000s
- Full-scale demonstration plants in South Africa and Portugal in late 2000s
- Application for scaled-up domestic sewage treatment plants from 2010

WWTP in Epe, the Netherlands (2010~)

WWTP in Garmerwolde, the Netherlands (2010~)

Anaerobic Fluidized Bed Membrane Bioreactor



J. Kim, …, P. L. McCarty and J. Bae, ES&T, 2011.

AFMBR: Concept & advantages

- Concept
  - Two-step anaerobic process for low-strength wastewater
  - Granular activated carbon (GAC) as media for attached growth
  - Membrane filtration for solid/liquid separation
- Pilot scale demonstration successful, with acceptable effluent quality
- Advantages
  - Those for MBR apply

  \+ Energy recovery (CH_4)

  \+ No aeration requirements

  \+ Removal of refractory organics via GAC adsorption