ENVE 302
Environmental Engineering Unit Processes

CHAPTER 10

Biological Phosphorus Removal (BPR)

Assist. Prof. Bilge Alpaslan Kocamemi
Marmara University
Department of Environmental Engineering
Istanbul, Turkey

BIOLOGICAL PHOSPHORUS REMOVAL

Phosphorus removal is done to central eutrophication.

In early designs → chemical treatment using alum and iron salts is the most currently used technology for phosphorus removal.

Advantage of biological P removal → reduced chemical cost

less sludge production as compared to chemical precipitation.

Biological Phosphorus Removal

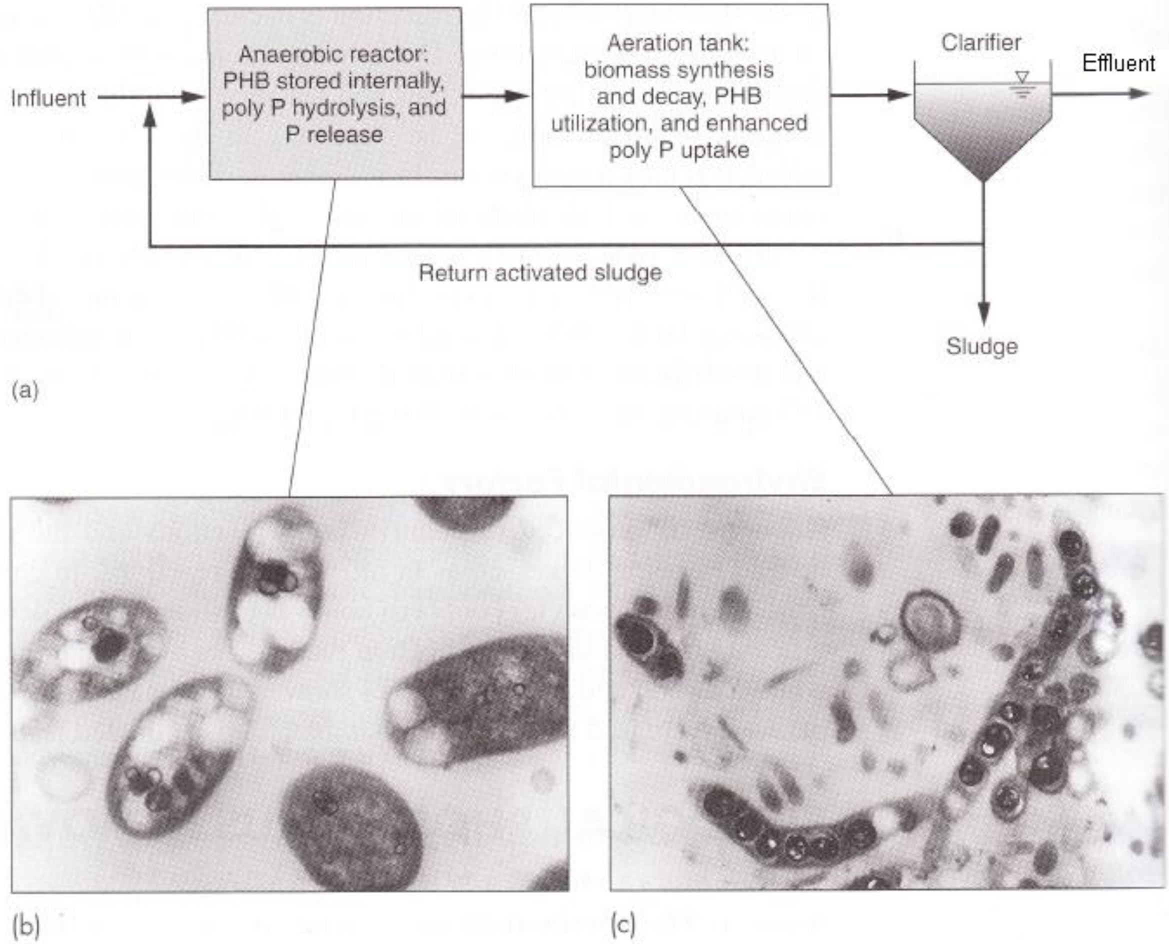

Figure 7-22

Biological phosphorus removal: (*a*) typical reactor configuration. Photos below flow diagram are of (*b*) transmission electron microscope images of polyhydroxybutyrate storage and (*c*) polyphosphate storage granules.

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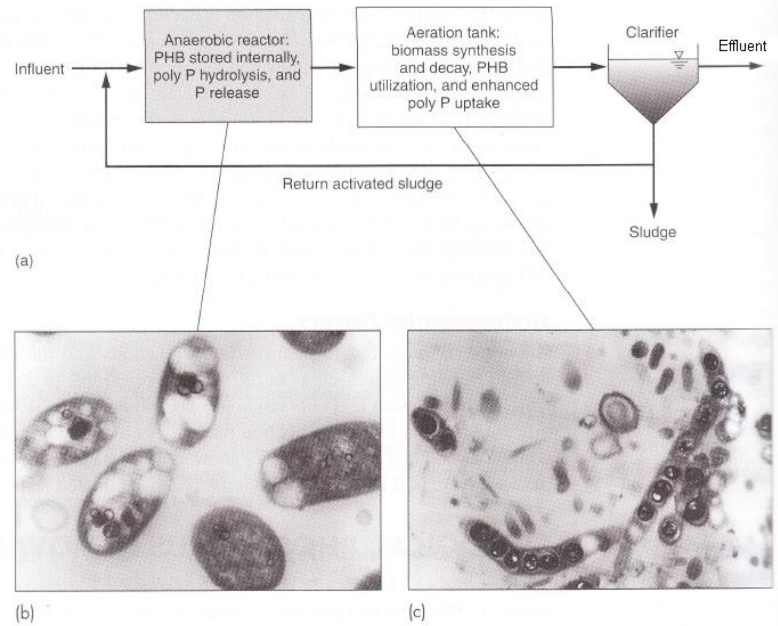
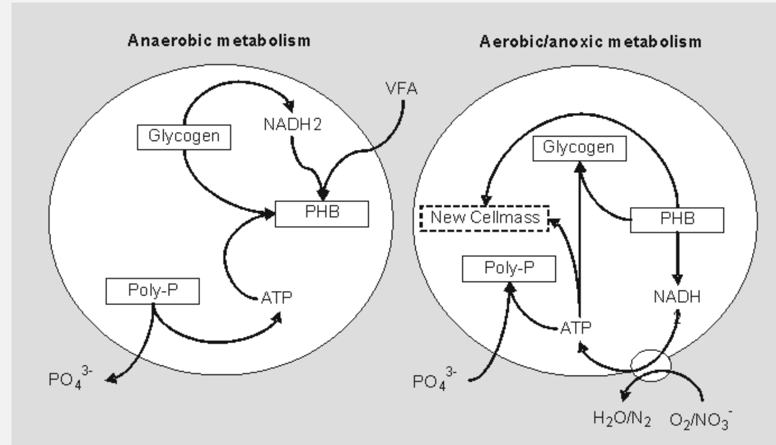
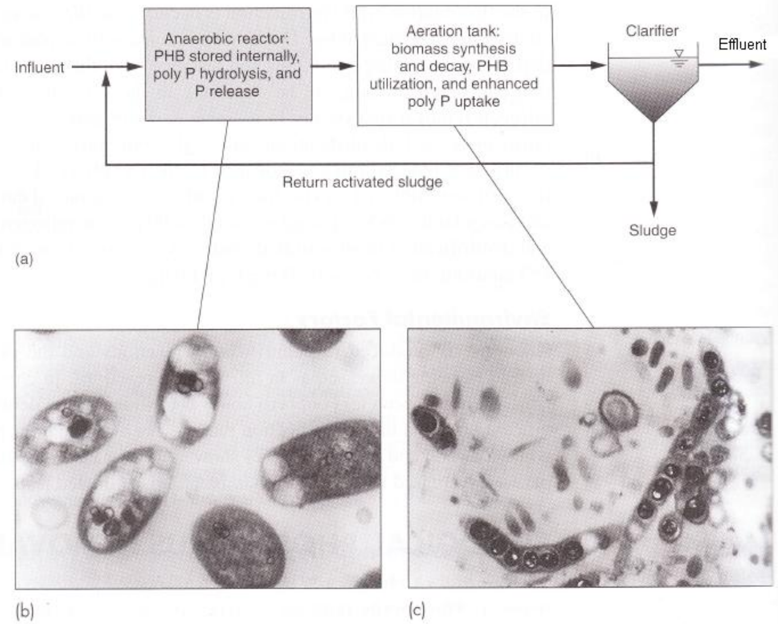




In anaerobic reactor ;

- Short chain VFA, particularly acetate play central role.
  (Acetate produced by fermentation of bsCOD)
- Phosphorus Accumulating Organisms (PAO) are encouraged to grow.
- PAO using energy available from stored polyphosphates assimilate acetate and produce intercellular polydoxybutyrate (PHB) storage products.



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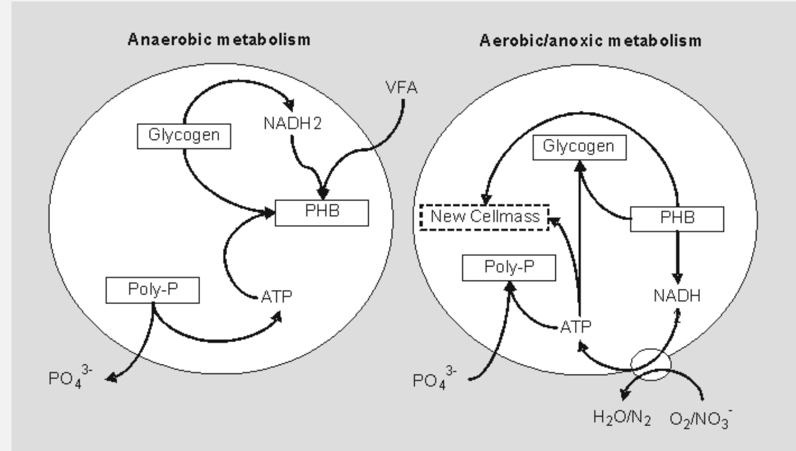
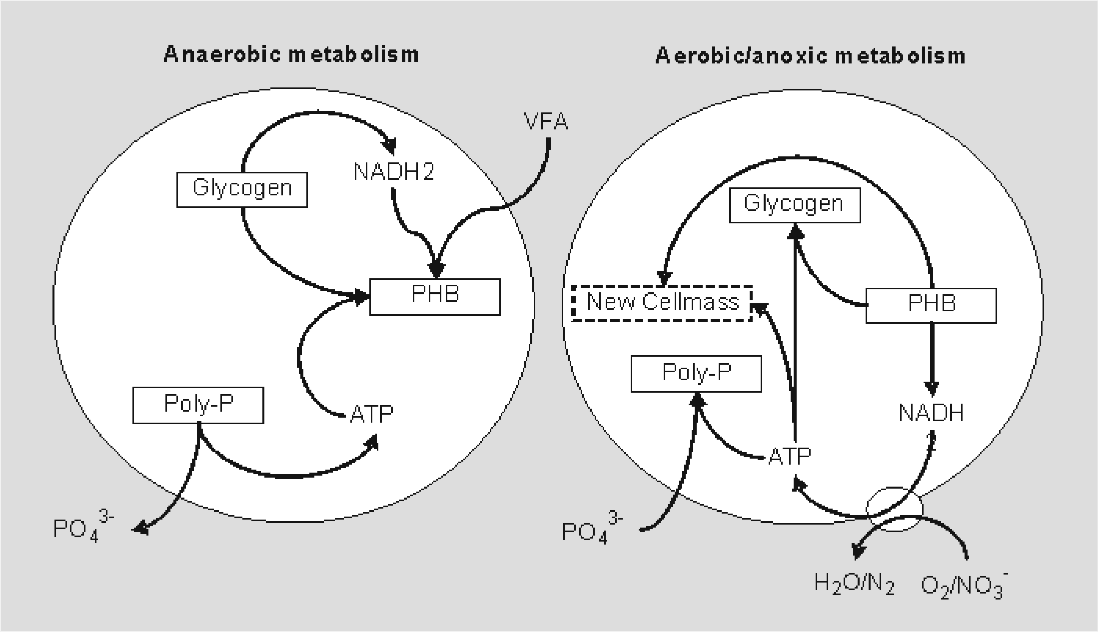


In aerobic zone;

The PHB stored in aerobic zone is used as source of organic carbon for new cell growth and thus providing energy.

The energy released from PHB oxidation is used to form polyphosphate bonds in cell storage so that soluble orthophosphate

($O\text{-}PO_4$) is removed from solution and incorporated into polyphosphates within the bacterial cell.



Under stressed condition (anaerobic condition) ⟶ Poly-P microorganisms use polyphosphate as energy source

Poly-P microorganism (PAO organism) ⟶ ability to store PHB in the anaerobic zone is provided thruogh release of P.

PHB stored in the anaerobic zone is utilized as the source of organic C and also used as the energy source for the fermentation of poly-P thus an excess P uptake occurs in the aerobic zone.

If sufficient amounts of DO and NO_3^- enter the aerobic zone

The acetate can be depleted before it is the up by PAOs and the treatment performance will be hindered.

Therefore,

biological phosphorus removal is not used in the systems that are designed with nitrification without including a means for denitrification to minimize the amount of nitrate in the return sludge flow to the anaerobic zone.

To control NO_3^- enterance to anaeorobic Bio-P basins via RAS:

RAS denitrification

STOICHOMETRY OF PHOSPHORUS REMOVAL

The amount of phosphorus removal $\longrightarrow$ estimated from the amount of bsCOD that is available in ww influent.

Most of bsCOD $\longrightarrow$ will be converted to acetate in the short anaerobic hydraulic retention time.

Assumptions used is evaluate the stoichometry of BPR;

- **1.06 g acetate /g bsCOD** will be produced as COD fermented $\longrightarrow$ VFA s

- a cell yield of **0.3 g VSS/g acetate**

- a cell phosphorus content **0.3 g P / g VSS**

Using these assumptions,

about 10 g of bsCOD will be required to remove 1 g of phosphorus biologically.

PROCESS DESIGN CONSIDERATIONS

1) Wastewater characterization:

Wastewater characterization including rbCOD measurement

Biological P removal $\longrightarrow$ iniatiated in the anaerobic zone where acetate is taken up by PAOs and converted to carbon storage products (PHB)

rbCOD $\rightarrow$ primary source of VFAs for the PAOs

Conversion of rbCOD$\rightarrow$ VFA occurs quickly through fermantation in the anaerobic zone.

7 – 10 mg acetate $\longrightarrow$ results in about 1 mg P removal

The more acetate, the more cell growth, more P removal.

- Diurnal variations in ww strength $\rightarrow$ important
  low influent ww strength $\rightarrow$ may effect BPR process

- Wet weather ,especially winter, conditions
  BPR may be diffucult to achieve due to cold, low strength ww that does not readily become anaerobic.

2)Anaerobic contact time:

Detention time of 0.25-1 hr are adequate for fermentation of rbCOD (typical 1.5 -2 hr)

1 d SRT → is recommended

Too long SRT ⟶ potential for **secondary release of P** which is P release not associated with acetate uptake.

When secondary release occurs ⟶ bacteria have not accumulated PHB for subsequent oxidation in aerobic zone.

For BPR;

Longer SRT biological nutrient removal systems → are less efficient than → Shorter SRT biological nutrient removal systems

Two adverse effects of long SRT

- Final amount of P removed is proportinal to the amount of biological P storing bacteria wasted.

→

- Long SRT → causes more extended endogeneous phase of phosphorus bacteria

  bacteria in endogeneous phase will deplete more of their intercellular storage products

If intercellular glycogen is depleted;

→ less efficient acetate uptake

→ less PHB storage in aerobic zone

→ overall BPR process will be less efficient.

4)Waste sludge processing:

Anaerobic conditions in thickening and/or digestion result in release of P

Thickening of waste sludge by DAF

→ gravity belt thickeners

→ rotary drum thickeners

is preferred over gravity thickening of waste sludge to minimize P release.

Also, wastage from aeration tank, not from RAS line →preferred

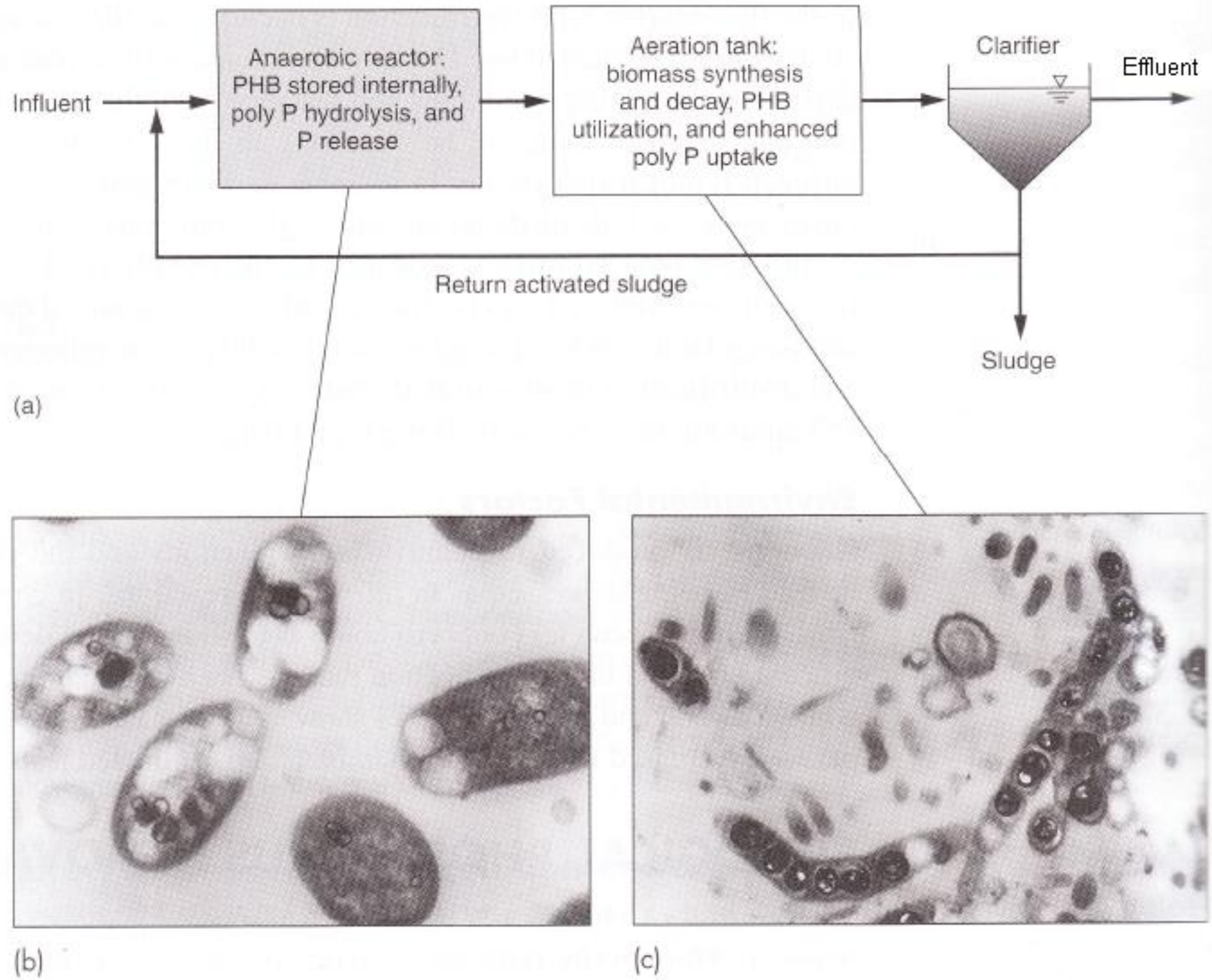
Methods to improve phosphorus removal efficiency in BPR systems

- Provide supplemental acetate by direct purchase of exogenous carbon source or by primary sludge fermantation in hydrolysis tank.

- Reduce the process SRT

- Reduce the amount of NO_3 and /or oxygen entering the anaerobic zone

BIOLOGICAL PHOSPHORUS REMOVAL



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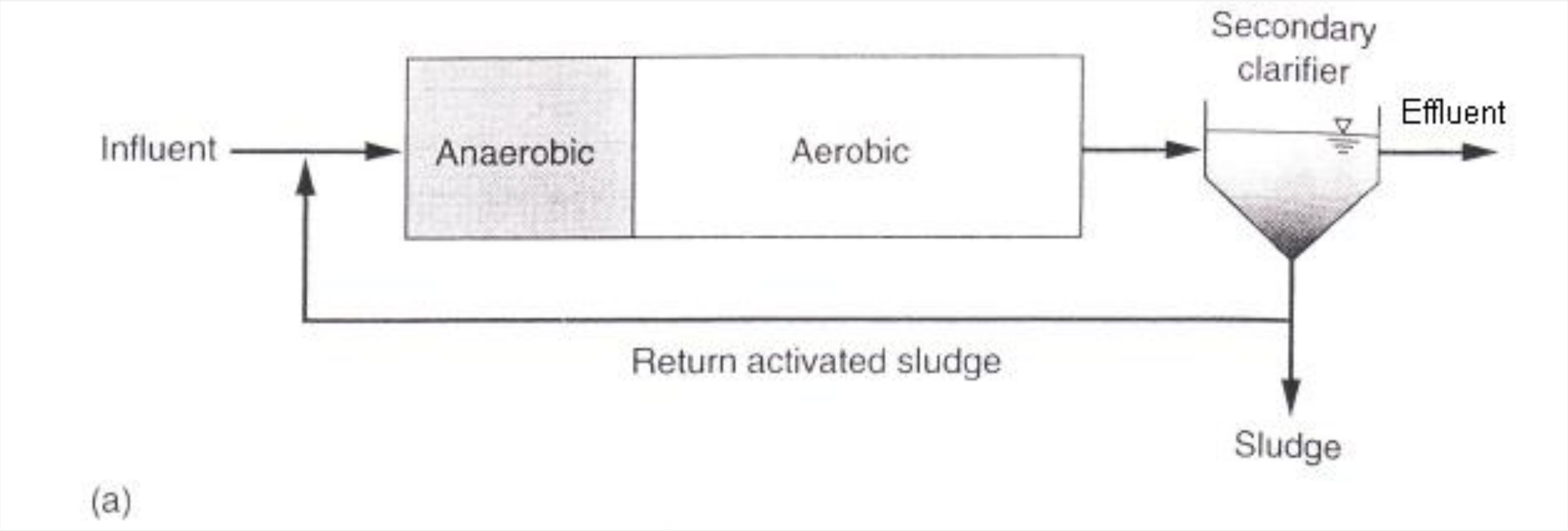
Biological phosphorus removal: (*a*) typical reactor configuration. Photos below flow diagram are of (*b*) transmission electron microscope images of polyhydroxybutyrate storage and (*c*) polyphosphate storage granules.

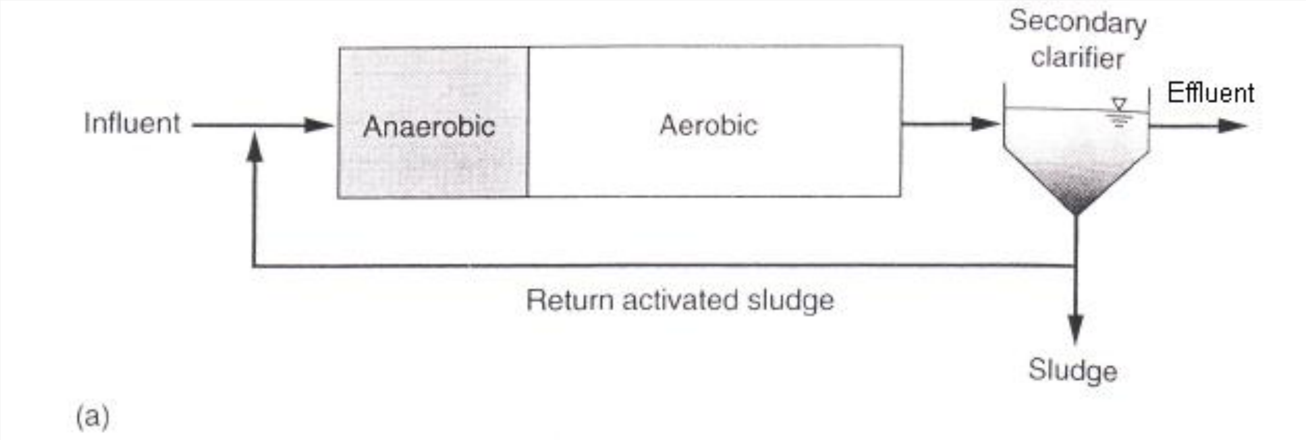
Ref: Metcalf & Eddy

Typical mainstream biological phosphorus removal processes

a) Phoredox (A/O)

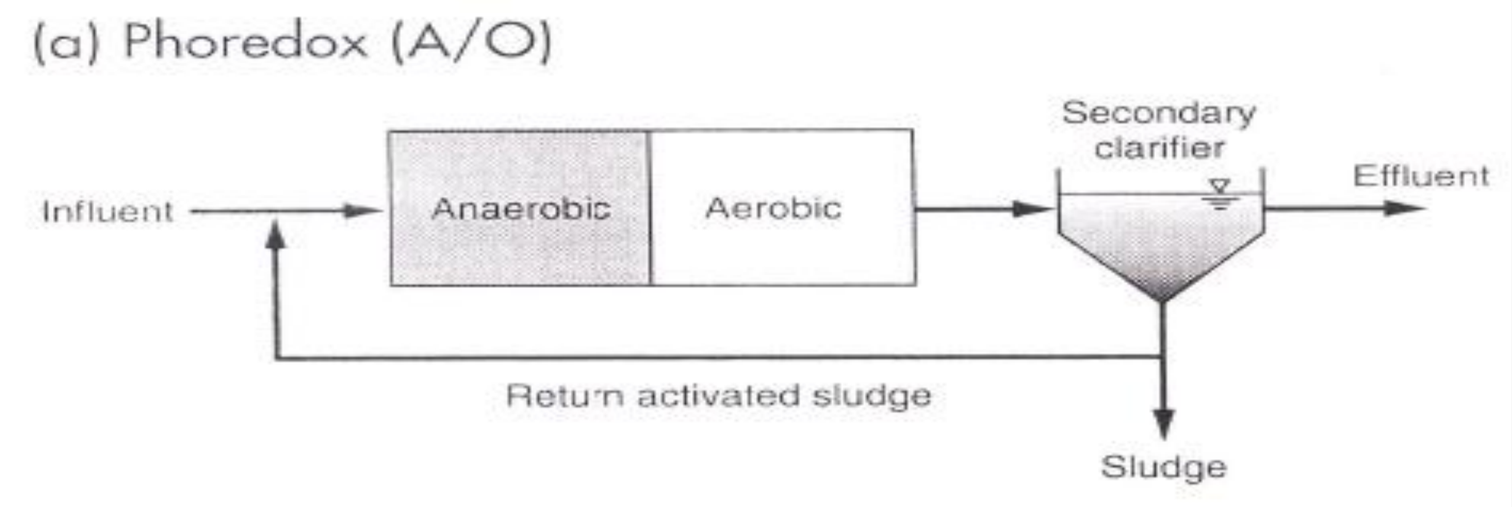


- Phosphorus and Carbon removal
- No nitrification
- Low operating SRT values are used to prevent initiation of nitrification



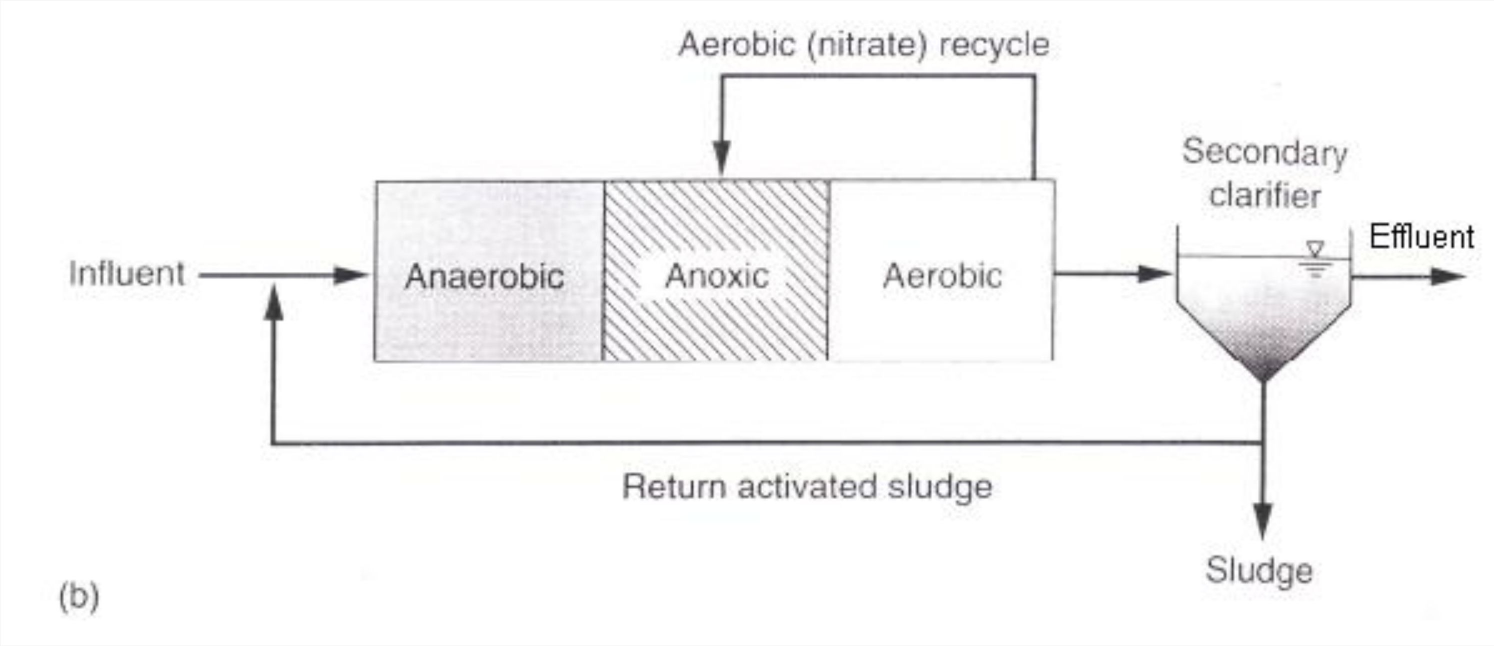
If nitrification occurs;

- NO_3-N enters to anaerobic zone by RAS recycle
- heterotrophic bacteria will use NO^-_3 to consume rbCOD in the anaerobic zone
- rbCOD available for phosphorus-storing bacteria will be less
- biological phosphorus removal treatment efficiency decreases



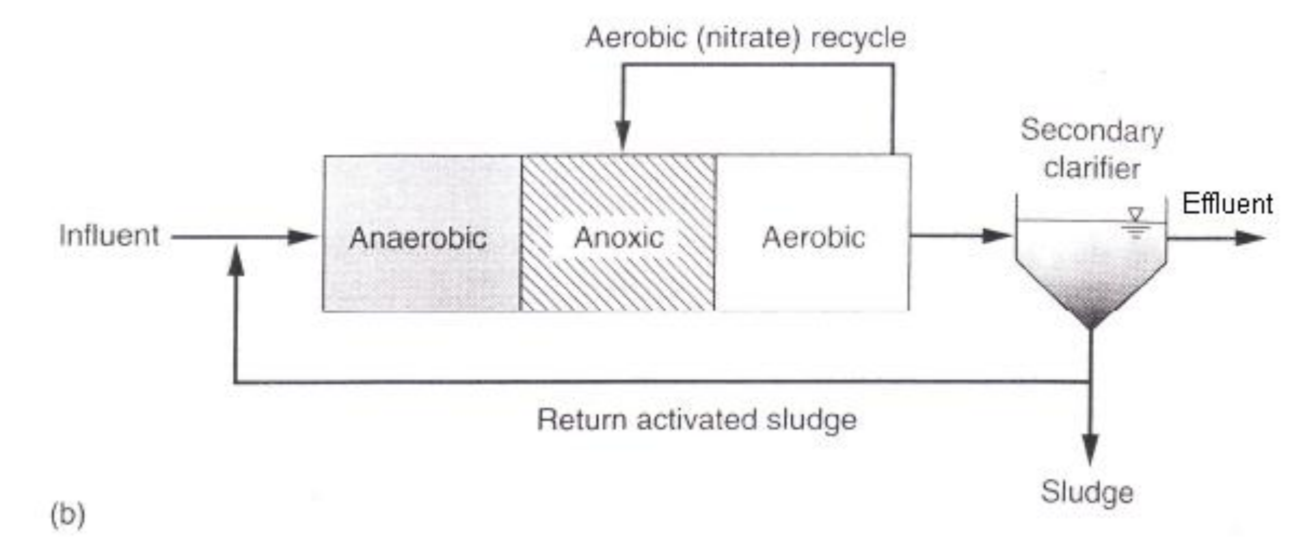
The basic process configuration for biological phosphorus removal consists of an anaerobic zone followed by an aerobic zone. Barnard (1974) was the first to clarify the need for anaerobic contacting between activated sludge and influent wastewater before aerobic degradation to accomplish biological phosphorus removal. Barnard identified it as the Phoredox process. The A/O process is a patented version of Barnard's findings by Air Products and Chemicals, Inc., and the main difference is the use of multiple-staged anaerobic and aerobic reactors. In these processes there is no nitrification, and the anaerobic detention time is 30 min to 1 h to provide the selective condition described in Sec. 7–11 for biological phosphorus removal. The SRT of the aerobic zone mixed liquor is 2 to 4 d, depending on the temperature

b) A^2/O



- Phosphorus - Carbon - Nitrogen removal

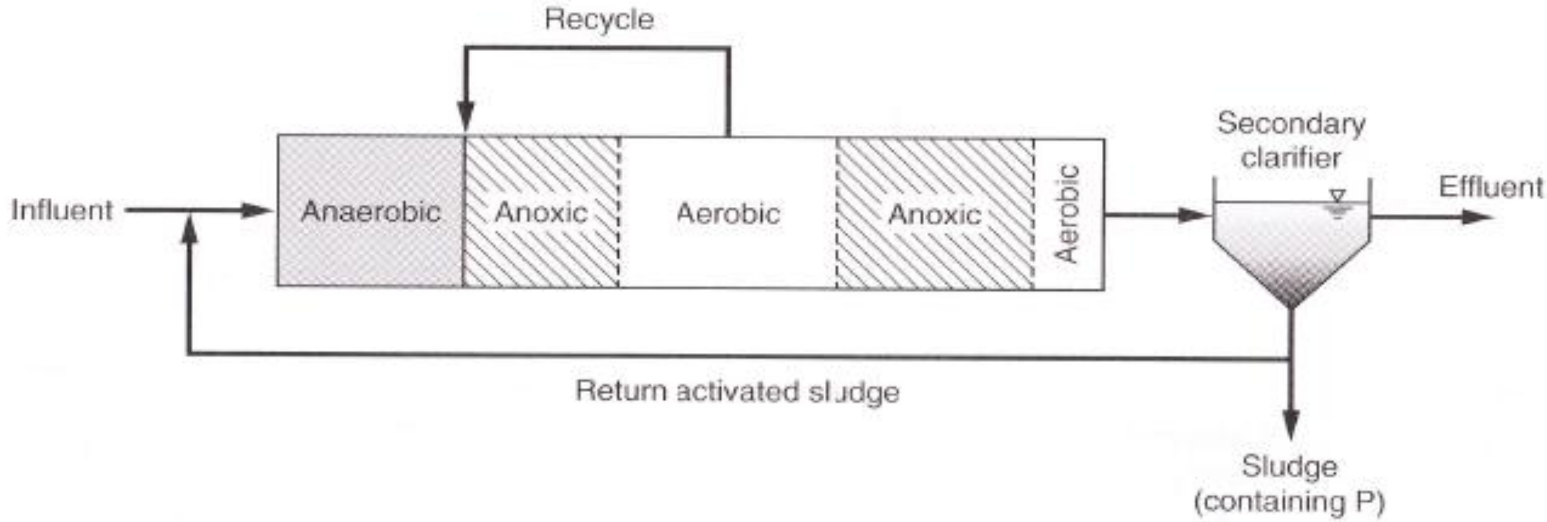
- Use of anoxic zone minimizes the amount of NO^-_3 feed to anaerobic zone through RAS recycle



The proprietary A^2/O process is a modification of the A/O process and provides an anoxic zone for denitrification. The detention period in the anoxic zone is approximately 1 h. The anoxic zone is deficient in dissolved oxygen, but chemically bound oxygen in the form of nitrate or nitrite is introduced by recycling nitrified mixed liquor from the aerobic section. Use of the anoxic zone minimizes the amount of nitrate fed to the anaerobic zone in the return activated sludge

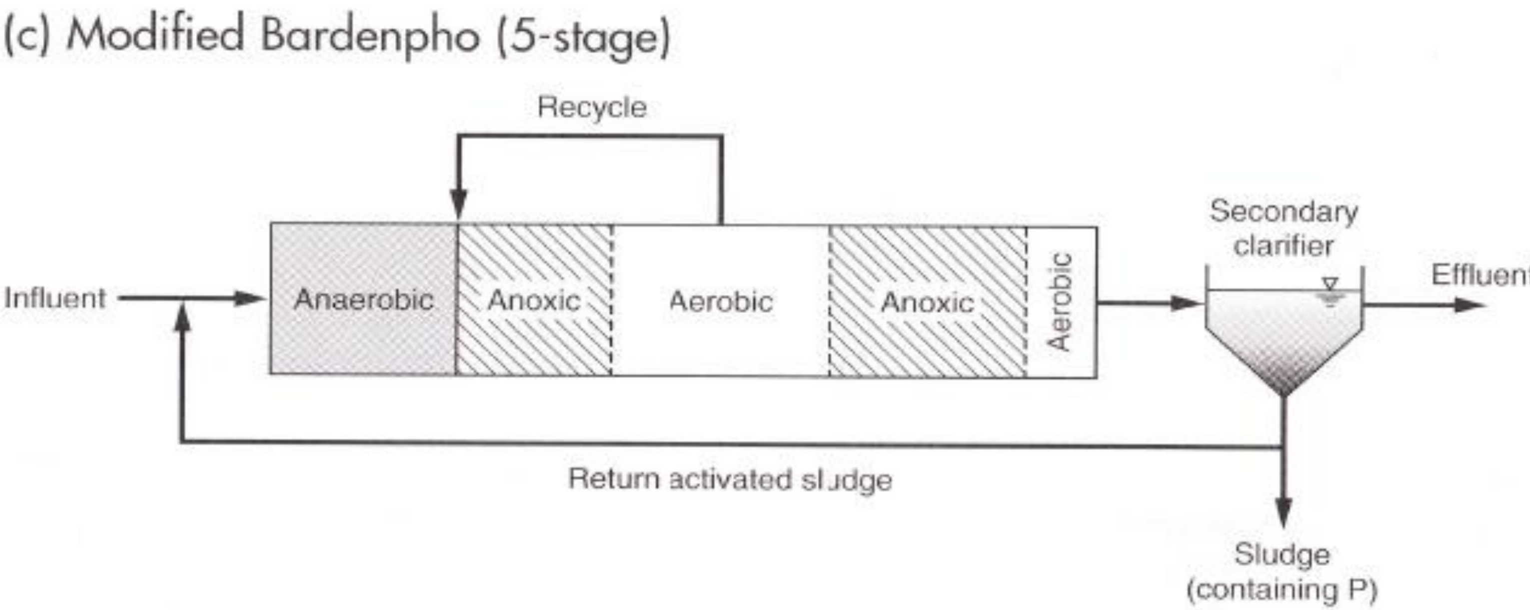
Ref: Metcalf & Eddy

c) Modified Bardenpho (5-stage)



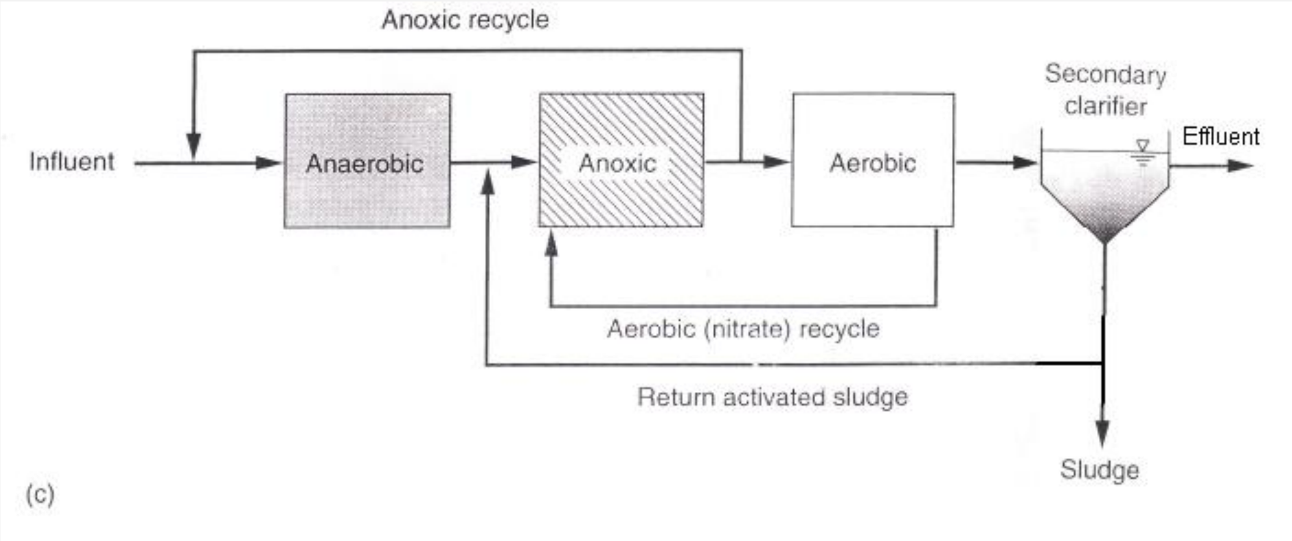
- Phosphorus - Carbon - Nitrogen removal

Ref: Metcalf & Eddy



combined nitrogen and phosphorus removal. The staging sequence and recycle method are different from the A^2/O process. The 5-stage system provides anaerobic, anoxic, and aerobic stages for phosphorus, nitrogen, and carbon removal. A second anoxic stage is provided for additional denitrification using nitrate produced in the aerobic stage as the electron acceptor, and the endogenous organic carbon as the electron donor. The final aerobic stage is used to strip residual nitrogen gas from solution and to minimize the release of phosphorus in the final clarifier. Mixed liquor from the first aerobic zone is recycled to the anoxic zone. The 5-stage process uses a longer SRT (10 to 20 days) than the A^2/O process, and thus increases the carbon oxidation capability

d) University of Cape Town (UCT)



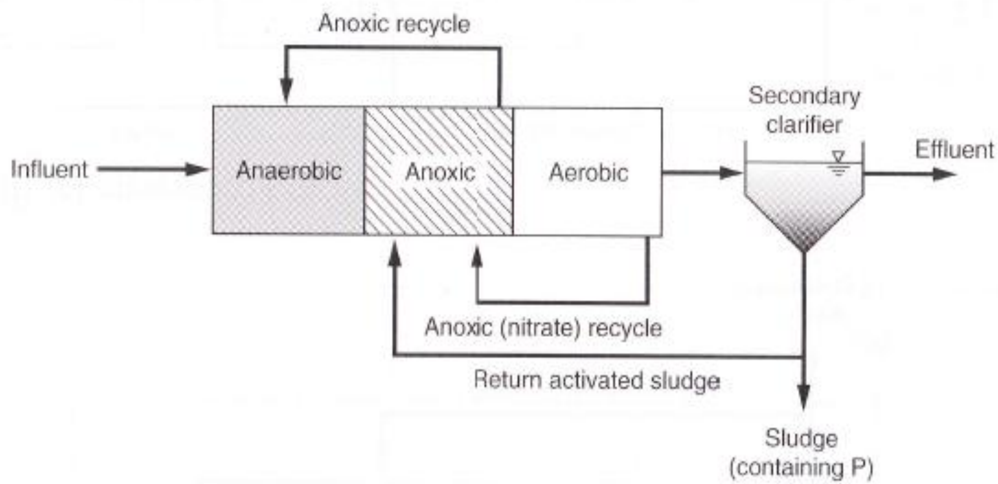
are used for relatively weak ww where NO^-_3 would have a significant effect on BPR

RAS recycle to anoxic zone

Mixed liquor recycle to anaeorobic zone drawn following to anoxic zone:

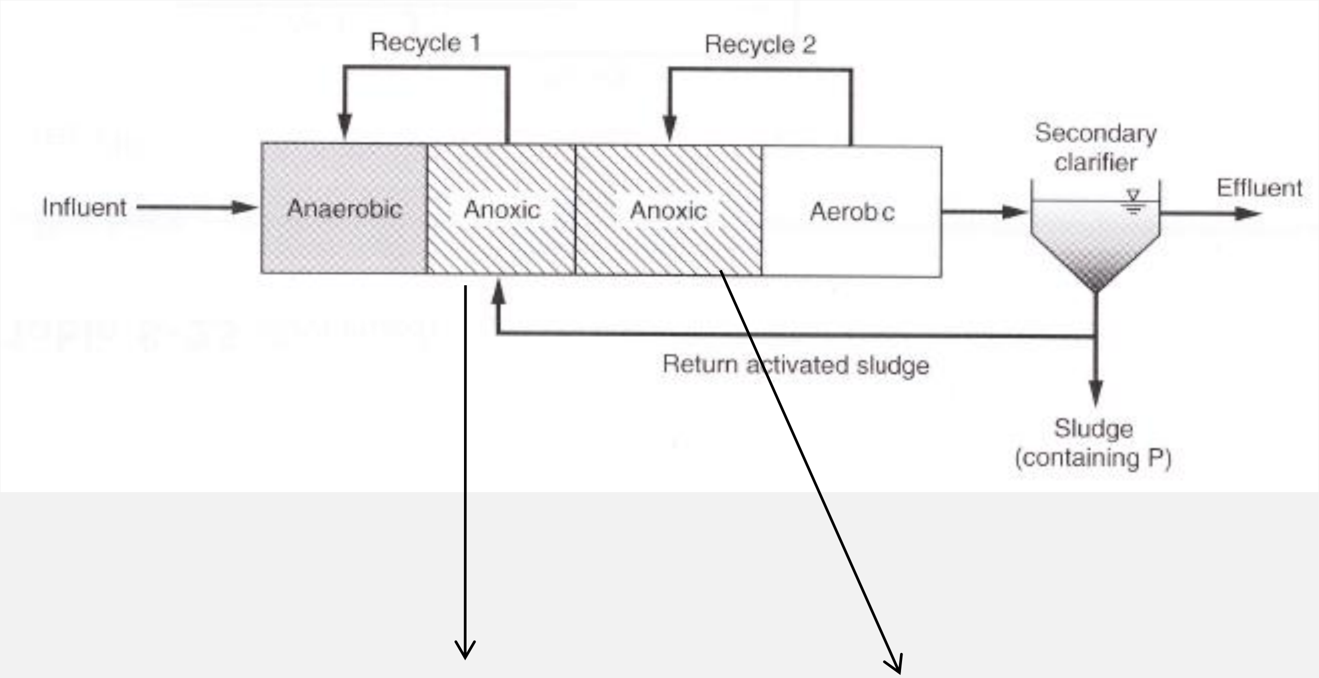
to minimize NO^-_3 concentration entering to anaerobic zone

(d) UCT (standard and modified)



The UCT process stands for the University of Cape Town (South Africa) treatment process where it was developed. The UCT process was developed to minimize the effect of nitrate in weaker wastewaters in entering the anaerobic contact zone. The amount of nitrate in the anaerobic zone is critical to the biological phosphorus-removal efficiency. The UCT process is similar to the A^2/O process with two exceptions. The return activated sludge is recycled to the anoxic stage instead of the aeration stage, and the internal recycle is from the anoxic stage to the anaerobic stage. By returning the activated sludge to the anoxic stage, the introduction of nitrate to the anaerobic stage is eliminated, thereby improving the uptake of phosphorus in the anaerobic stage. The internal recycle feature provides for increased organic utilization in the anaerobic stage. The mixed liquor from the anoxic stage contains substantial soluble BOD but little nitrate. The recycle of the anoxic mixed liquor provides for optimal conditions for fermentation uptake in the anaerobic stage. Because the mixed liquor is at a lower concentration, the anaerobic detention time must be longer than that used in the Phoredox process, and is in the range of 1 to 2 h. The anaerobic recycle rate is typically 2 times the influent flowrate

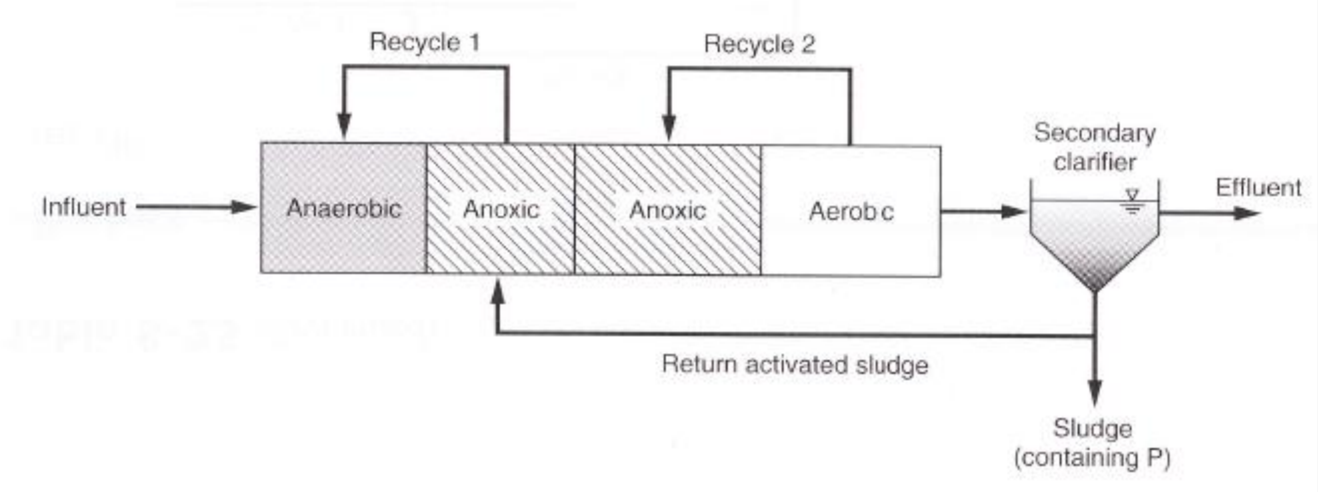
d) UCT (modified)



To minimize NO_3^- concentration in the mixed-liquor recycle to anaerobic zone

Major portion of NO_3^- removal occurs in this zone

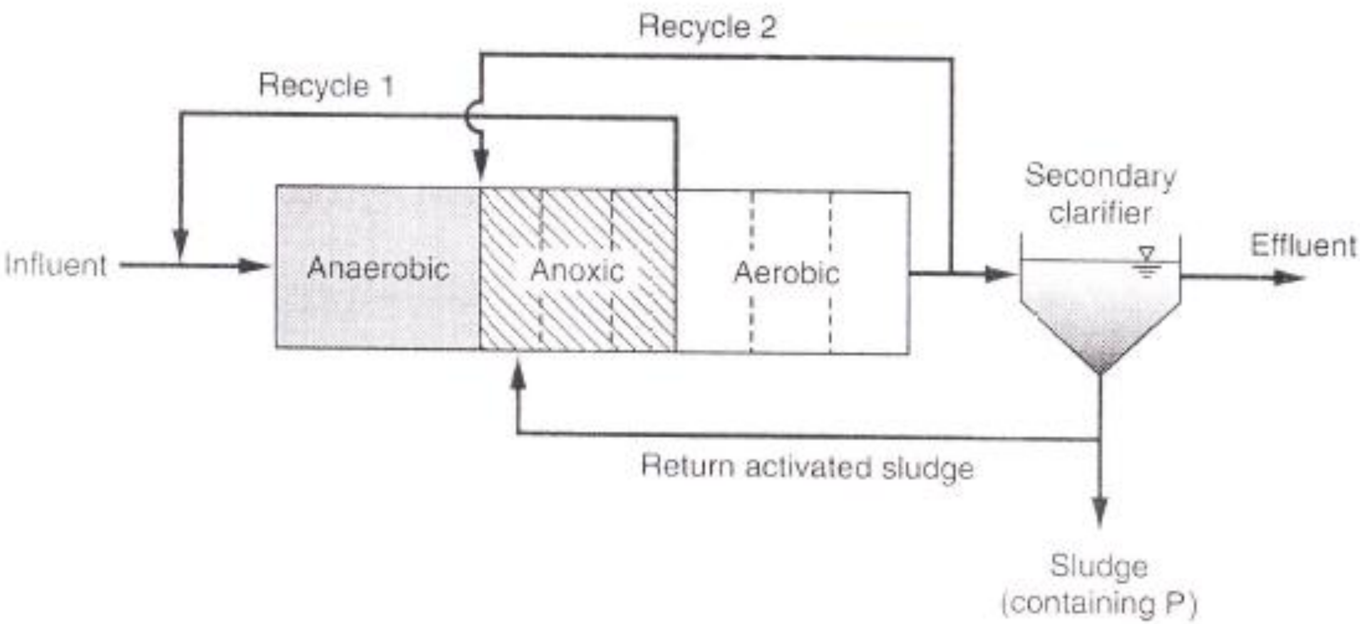
Ref: Metcalf & Eddy



In the modified UCT process shown on the second diagram, the return activated sludge is directed to an anoxic reactor that does not receive internal nitrate recycle flow. The nitrate is reduced in this tank, and the mixed liquor from the reactor is recycled to the anaerobic tank. The second anoxic tank follows the first anoxic tank and receives internal nitrate recycle flow from the aeration tank to provide the major portion of nitrate removal for the process

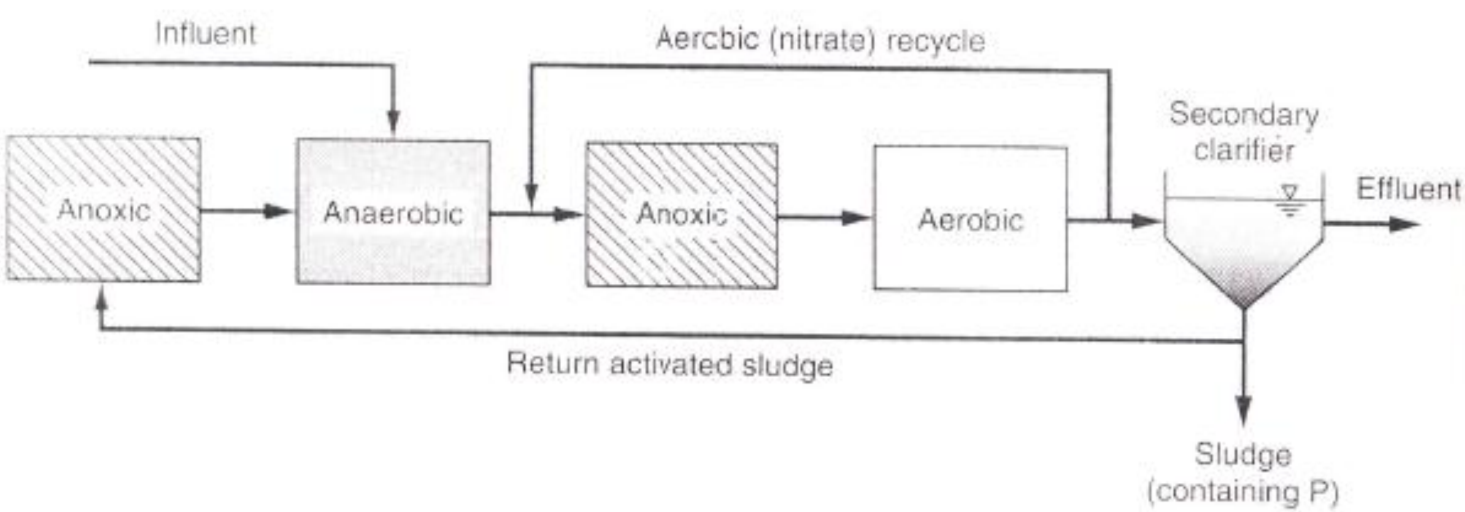
Ref: Metcalf & Eddy

(e) VIP



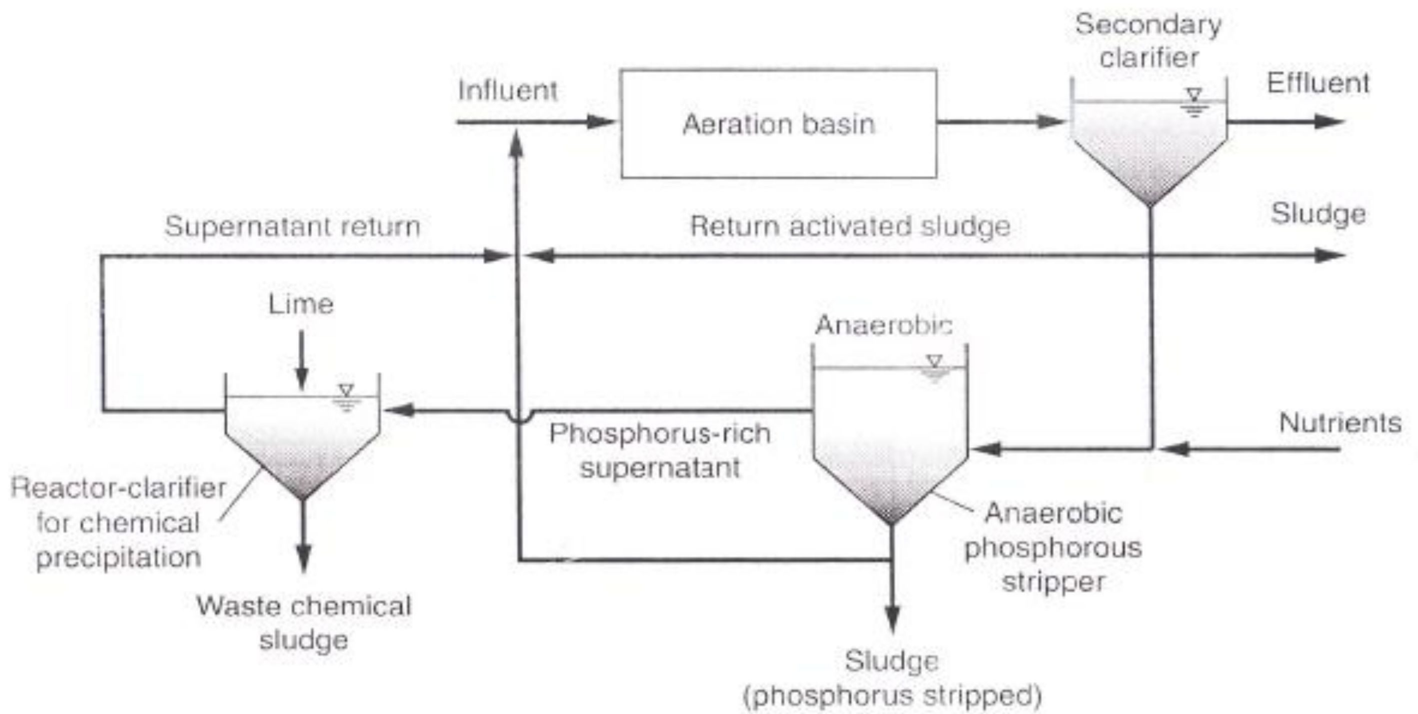
The VIP process stands for the Virginia Initiative Plant (Daigger et al., 1988). The VIP process is similar to the A^2/O and UCT processes except for the methods used for recycle systems. In the VIP process, all the zones are staged consisting of at least two completely mixed cells in series. The return activated sludge is discharged to the inlet of the anoxic zone along with nitrified recycle from the aerobic zone. The mixed liquor from the anoxic zone is returned to the head end of the anaerobic zone. The VIP process is also designed as a high-rate system, operating with much shorter SRTs, which maximize biological phosphorus-removal efficiency. The combined SRT of the anaerobic and anoxic zones is generally 1.5 to 3 d, while the anaerobic and anoxic τ values are typically 60 to 90 min each. The aeration zone is designed for nitrification

(f) Johannesburg process



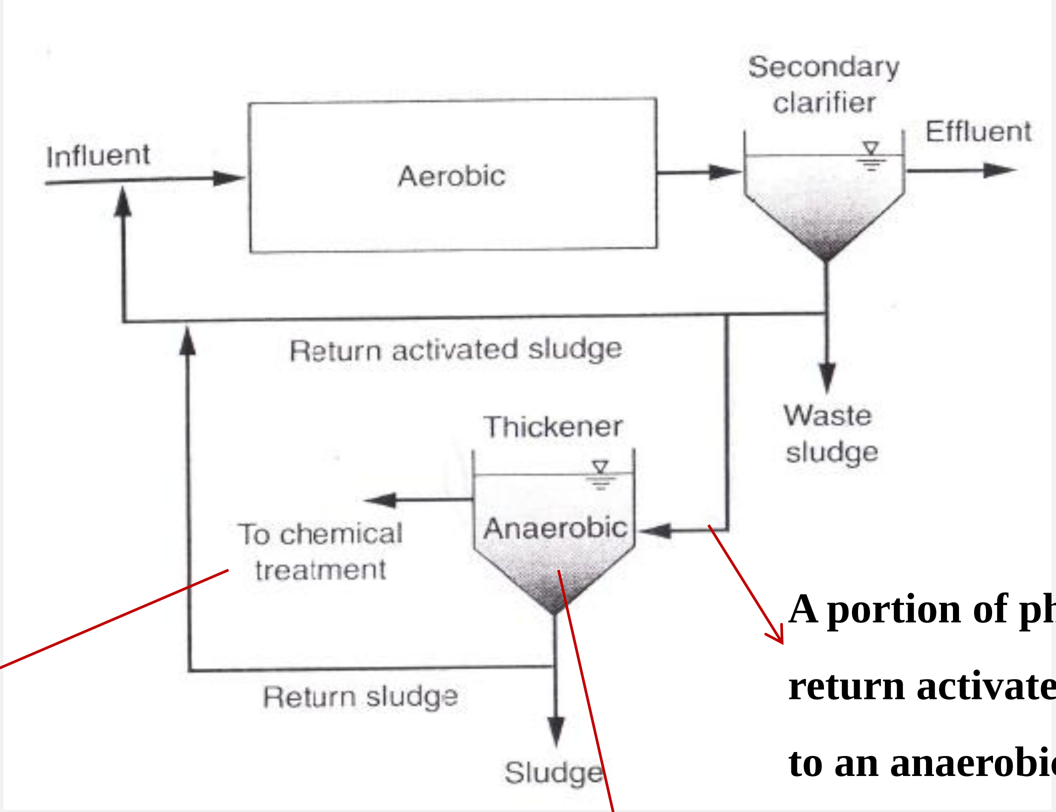
The process, which originated in Johannesburg, South Africa, is an alternative to the UCT or modified UCT processes to minimize nitrate feeding to the anaerobic zone to maximize biological phosphorus removal for weak wastewaters. The return activated sludge is directed to an anoxic zone that has sufficient detention time to reduce the nitrate in the mixed liquor before it is fed to the anaerobic zone. The nitrate reduction is driven by the endogenous respiration rate of the mixed liquor, and the anoxic zone detention time depends on the mixed liquor concentration, temperature, and the nitrate concentration in the return sludge stream. Compared to the UCT process, a higher MLSS concentration can be maintained in the anaerobic zone, which has a detention time of about 1 h

(h) PhoStrip



Side-stream process

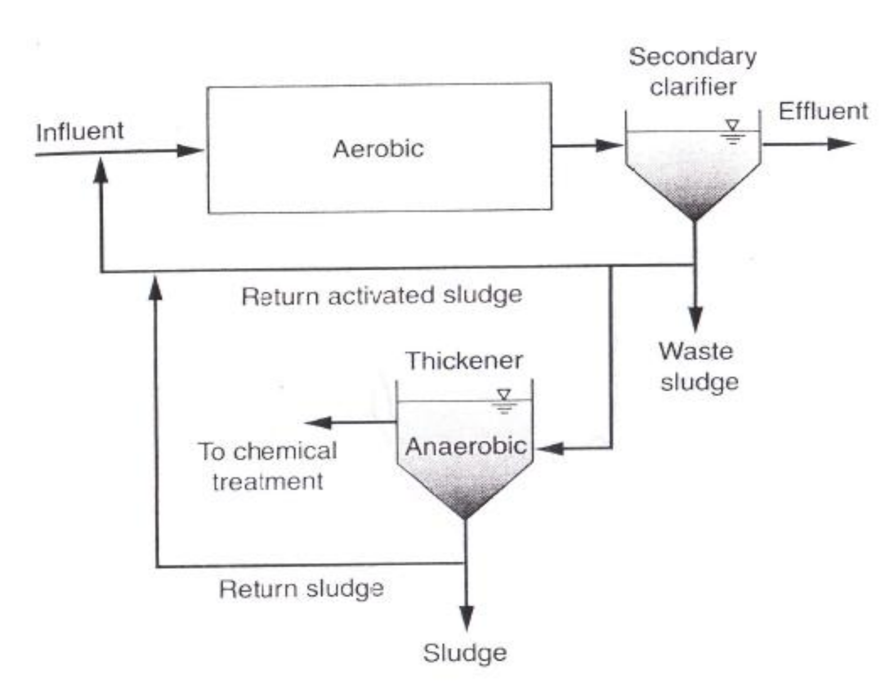
PhoStrip



Phosphorus-rich supernatant of anaerobic tank is then precipitated with lime

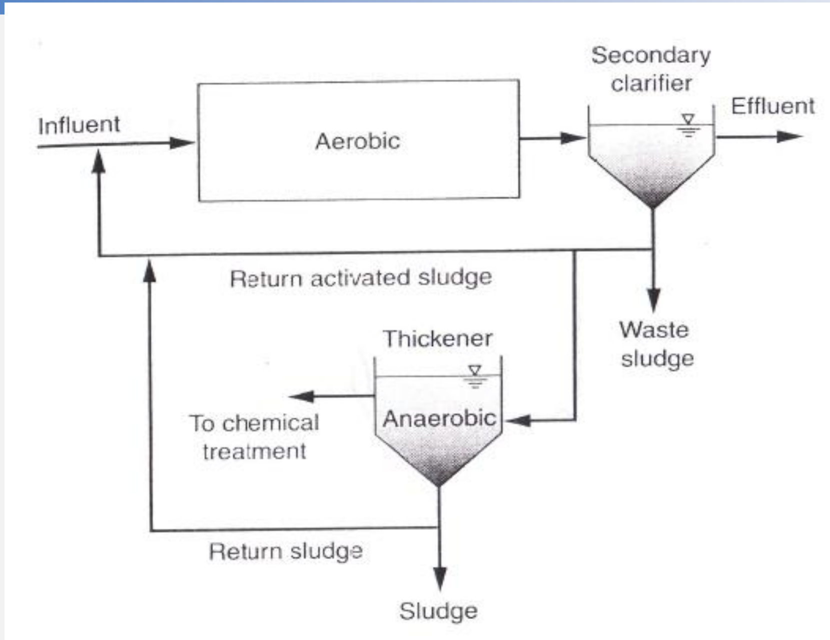
A portion of phosphorus-rich return activated sludge is diverted to an anaerobic stripping tank where phosphorus is released in solution

Avg SRT 5-20 hr



Fermentation products for the PAO :

- May be derived from the metaboism of hydrolyzed solids
- May be derived from organics released from lysed bacteria

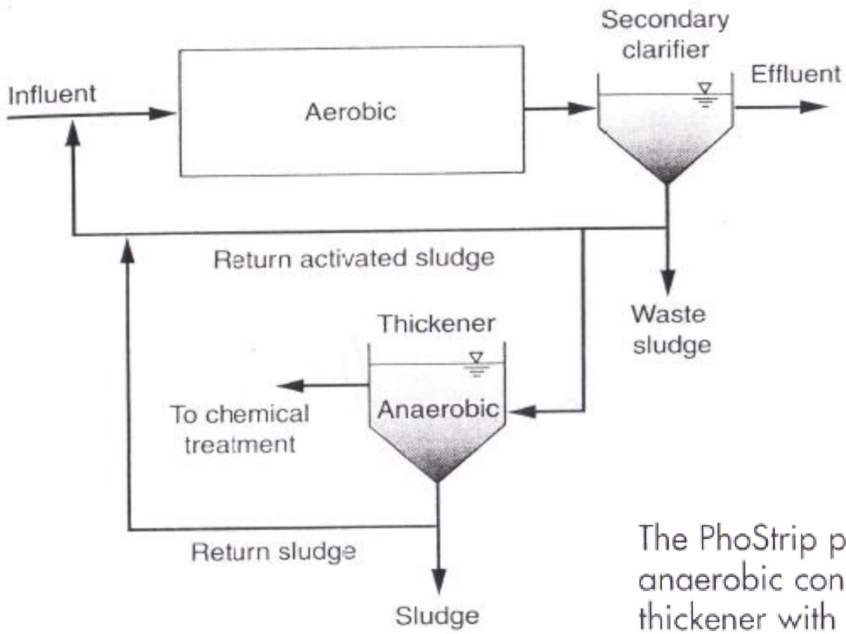


In PhoStrip process, phosphorus - removal efficiency depends less on the influent rbCOD concentrations than for other biological phosphorus – removal processes

- Can be easily incorporated into exsiting activated sludge plants.

- Significantly less chemical usage than main-stream chemical precipitation process

Effluent concentrations of less than 1 mg/L total P can be achieved with less dependence on the BOD strength of influent ww.



The PhoStrip process is in essence an anaerobic/aerobic process. The anaerobic condition is created by holding RAS long enough in a gravity thickener with residence times generally in the range of 8 to 12 h (Levin et al., 1975). The released phosphorus is elutriated, usually by adding primary effluent or raw wastewater, which also enhances the anaerobic condition. The overflow from the stripper tank is then treated chemically for phosphorus removal and the RAS is directed to the aerobic tank. Lime is usually used as a chemical to precipitate phosphorus from the stripper tank overflow. The lime dose needed to raise the pH for phosphorus removal is a function of the wastewater alkalinity and not the amount of phosphorus present. If alum and ferric salts are used instead, the dose is proportional to the amount of phosphorus released. Even though chemical treatment is used for phosphorus removal, there is some enhanced phosphorus removal in the waste sludge due to the development of phosphorus-storing bacteria. As shown, the phosphorus-removal performance would be hindered by nitrification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Typical design parameters for commonly used biological phosphorus-removal processes[a]

Design parameter/process	SRT, d	MLSS, mg/L	τ, h Anaerobic zone	Anoxic zone	Aerobic zone	RAS, % of influent	Internal recycle, % of influent
A/O	2–5	3000–4000	0.5–1.5	—	1–3	25–100	
A^2/O	5–25	3000–4000	0.5–1.5	0.5–1	4–8	25–100	100–400
UCT	10–25	3000–4000	1–2	2–4	4–12	80–100	200–400 (anoxic) 100–300 (aerobic)
VIP	5–10	2000–4000	1–2	1–2	4–6	80–100	100–200 (anoxic) 100–300 (aerobic)
Bardenpho (5-stage)	10–20	3000–4000	0.5–1.5	1–3 (1st stage) 2–4 (2nd stage)	4–12 (1st stage) 0.5–1 (2nd stage)	50–100	200–400
PhoStrip	5–20	1000–3000	8–12		4–10	50–100	10–20
SBR	20–40	3000–4000	1.5–3	1–3	2–4		

[a] Adapted from WEF (1998).