

PHOSPHOROUS REMOVAL : A COMPARATIVE STUDY OF BIOLOGICAL V/S PHYSICO CHEMICAL PROCESSES

By

Nida Maqbool¹

INTRODUCTION:

Phosphorus entry as a result of waste water emitted from the municipal as well as industrial waste water causes excessive eutrophication of lakes, reservoirs and ponds. Phosphorus is the main nutrient for the growth of aquatic micro organisms like algae. Phosphorus is the main rate limiting factor for the growth of algae in freshwater systems (Cummings et al, 2010). Since 1970 removal of Phosphorus is becoming increasingly popular. Although phosphorus is present in low concentrations but its release to the water bodies is of environmental significance. (Georgants et al, 2005) Total removal or at least a significant reduction of phosphorus is obligatory, if not always fulfilled, in most countries (Bashan et al, 2003). There are no phosphorus-phosphate standards in National Environmental Quality Standards for Municipal and Liquid Industrial Effluents of Pakistan, however, WHO and USEPA standards are being used as reference.

Many countries set 1 mg/L and 2 mg/L as the limit for total phosphorus concentrations in discharges of waste water treatment plants. One of the reasons for this low limit is that P concentrations below 0.5 mg/L have been shown to be the limiting value for algal growth (Dryden and Stern, 1968), i.e., at P concentrations below 0.5 mg/L algal growth in a natural, fresh water environment is essentially inhibited or blocked. This notwithstanding, requirements for waste water treatment plants are being made ever more stringent, such that herein we consider a range of plant designs that would meet limits of between 0.05 and 2.00 mg/L of total phosphorus in their effluents. The EPA water quality criteria states that phosphates should not exceed .05 mg/l if streams discharge into lakes or reservoirs, .025 mg/l within a lake or reservoir, and .1 mg/l in streams or flowing waters not discharging into lakes or reservoirs to control algal growth. Surface waters that are maintained at .01 to .03 mg/l of total phosphorus tend to remain uncontaminated by algal blooms. This comprehensive review summarizes the current status in phosphorus-removal technologies from the most common approaches like Biological, Chemical, Physical and combination of above.

To remove the phosphorus up to the stringent goals one must have more knowledge about the types of species found in waste water (Scherrenberg et al, 2008). There are mainly four types of Phosphorus species:

1. Orthophosphates.
2. Metal bound Phosphates.
3. Dissolved Organic Phosphorus.
4. Particulate Organic Phosphorus.

1. Graduate Student at IESE, NUST, Islamabad.

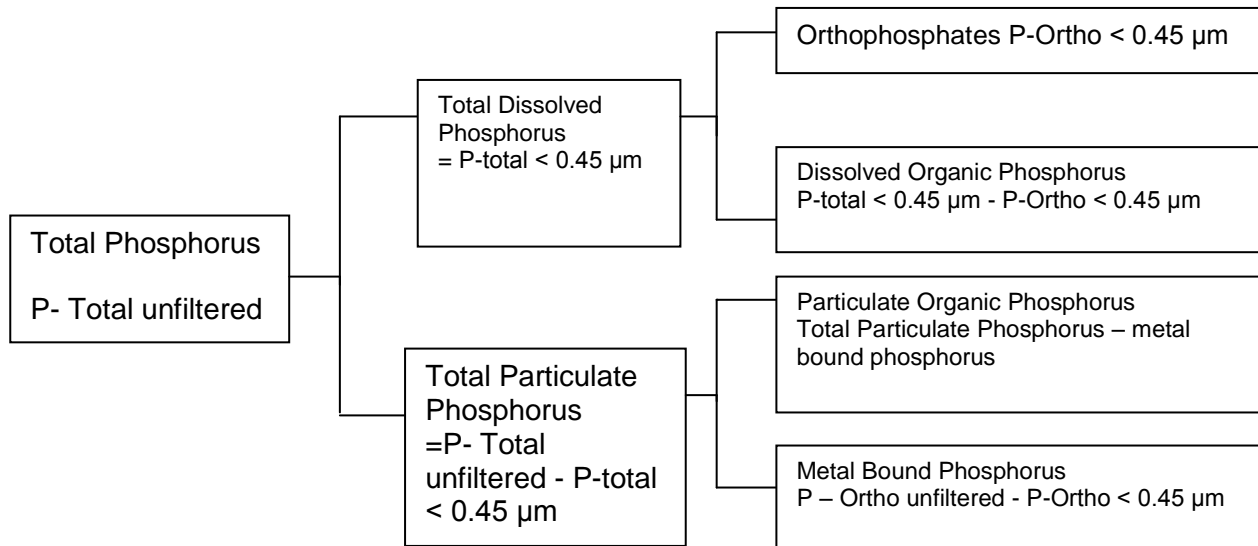


Figure 1. Phosphorus Distribution

PROCESSES FOR REMOVAL OF PHOSPHORUS:

Several unit processes have been developed for elimination of phosphorus. These include biological nutrient removal (BNR) (Lee *et al*, 1997), enhanced biological phosphorus removal (EBPR) (Smolders *et al*, 1996; Wild *et al*, 1996), crystallization (Van Dijk *et al*, 1984; Battistoni *et al*, 1997; Joko, 1984; Momberg *et al*, 1992; Munch *et al*, 2001), and activated aluminum adsorption (Donnert *et al*, 1999; Brattebø *et al*, 1986; Hano *et al*, 1997). The main list of the processes is as under:

1. PHYSICAL PROCESSES:

1. Filtration for Particulate Phosphorus
2. Membrane technologies

2. BIOLOGICAL PROCESSES:

1. Biological Phosphorus Removal (BPR)
2. Enhanced Biological Phosphorus Removal (EBPR)
3. Phosphorus removal using iron and wood
4. Wetlands
5. One Stage Activated Sludge Process (AS)
6. Two stage activated sludge processes (AO)
7. Three stage activated sludge processes (AAO)

3. CHEMICAL PROCESSES:

Precipitation of Metal Salts

- Iron Phosphorus Precipitation
- Alum Phosphorus Precipitation
- Calcium Phosphorus Precipitation
- Magnesium Phosphorus Precipitation

4. Physico-Chemical Processes:

- P removal using dewatered alum sludge
- P removal using alum in liquid form
- P removal using spent alum sludge and reject water
- Three stage activated sludge with metal addition (AAO + M)
- Three stage activated sludge with metal addition and tertiary clarifiers (AAO +M + S)
- Three stage activated sludge with metal addition ,tertiary clarifiers and Filtration (AAO + M + S + F)
- Three stage activated sludge with tertiary clarifiers and activated aluminum adsorption (AAO + Al + S + C)
- Three stage activated sludge with metal addition, filter and membrane methods (AAO + Al + F + UF)

PHYSICAL PROCESSES:

1. FILTRATION FOR PARTICULATE-P:

Assuming that 2-3% of organic solids is P, then an effluent total suspended solids (TSS) of 20 mg/L represents 0.4-0.6 mg/L of effluent P (Strom, 2006). In plants with EBPR the P content is even higher. Thus sand filtration or other method of TSS removal (e.g., membrane, chemical precipitation) is likely necessary for plants with low effluent TP permits (Reardon, 2006).

2. MEMBRANE TECHNOLOGIES:

Membrane technologies have been of growing interest for waste water treatment in general, and most recently, for P removal in particular. In addition to removing the P in the TSS, membranes also can remove dissolved P. Membrane bioreactors (MBRs, which incorporate membrane technology in a suspended growth secondary treatment process), tertiary membrane filtration (after secondary treatment), and reverse osmosis (RO) systems have all been used in full-scale plants with good results. Reardon (2006) reported on several plants achieving <0.1 mg/L TP in their effluent, and suggested the current reliable limits of technology are 0.04 mg/L for MBRs and tertiary membrane filtration, and 0.008 mg/L for RO.

BIOLOGICAL PROCESSES:

1. BIOLOGICAL PHOSPHORUS REMOVAL (BPR):

Principle of Biological Phosphorus Removal:

For the biological removal of P in waste water certain types of micro organisms exist like Phosphorus Accumulating Organisms (PAOs) that preferentially uptake P present in soluble form in water. The mixed liquor is sent to anaerobic and then to the aerobic reactor. PAOs uptake/assimilate VFA (Volatile Fatty Acids) resulted in the fermentation occurring in the anaerobic digester. PAOs use the assimilated VFA as energy source in the aerobic reactor and assimilate Phosphorus thus reducing the amount of P in waste water.

In BPR systems, phosphorus accumulates in the biomass and is removed in the form of waste-activated sludge. A recent study showed that nearly all the enhanced phosphorus removal is due to the storage of polyphosphates.

2. ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL (EBPR):

Principle of Enhanced Biological Phosphorus Removal:

EBPR is a waste water treatment based on the selective enrichment of bacteria accumulating inorganic polyphosphate as an ingredient of their cells. It involves microbial metabolic cycling via several microbial-accumulated biopolymers (polyphosphate, PHA, and glycogen) (Bashan et al, 2004). This metabolic cycling is induced in microorganisms by alternating the incubation conditions of the waste water by

- Initially carbon-rich, strictly anaerobic incubation (no oxygen or nitrate are present)
- Followed by carbon-poor, aerobic incubation.

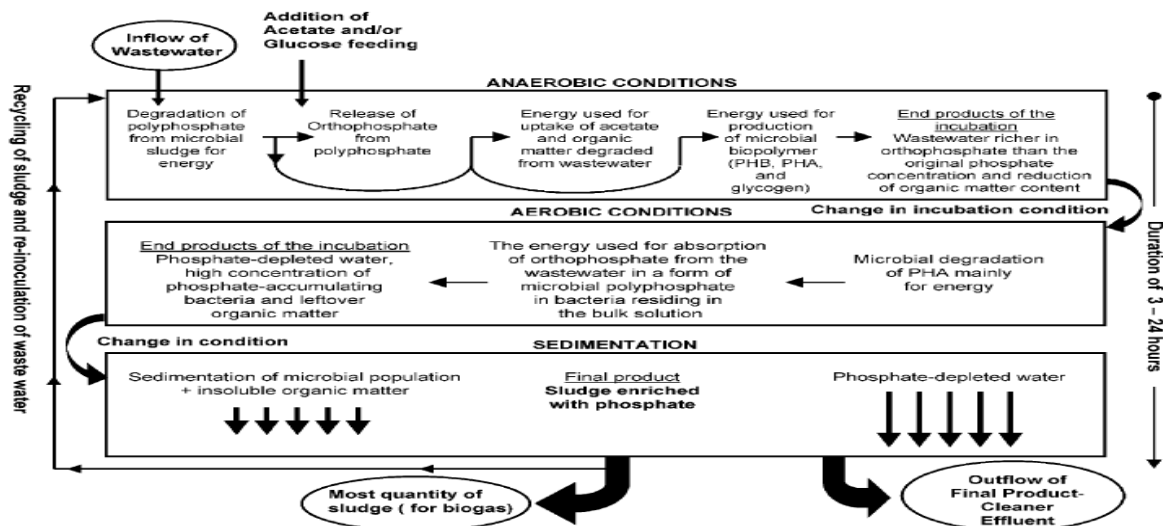


Figure 2. Conceptual Model for EBPR

Effect of Nutrients on EBPR:

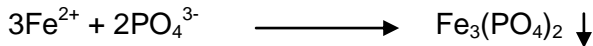
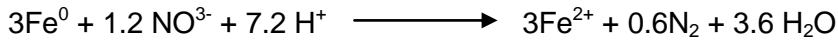
EBPR activated sludge has a reputation of variable performance due to the competition between the growth of PAOs (Phosphorus Accumulating Organisms) and GAOs (Glycogen Accumulating Organisms). The key factor in the competitive growth is specific type of VFA found in influent of the bio-reactor. The PAOs use Propionate more eagerly for their growth while the GAOs are more consented toward the presence of acetate. So, the secret to achieve reliable EBPR is to ensure the adequate supply of Propionate or an alternative substrate such as molasses that can be readily fermented to Propionate. (Thomas, 2008)

Effect of Environmental Parameters:

1. **pH** : findings from activated sludge of many WWTPs shows that there is an increase of 50-143% in level of orthophosphates uptake when pH is reduced to 5.5 rather than 7.5(McGrath *et al*, 2001)
2. **Retention Time** : adequate retention time is required for the enrichment of PAOs. So the initial anaerobic period should not be shortened during the start up of EBPR. Otherwise facultative bacteria start competing with the PAOs.
3. **Sludge Retention Time (SRT)** : for complete P removal no less than 15 days SRT is needed. (Merzouki *et al*, 2001)
4. **Excessive Aeration** : Excessive aeration (aeration during starvation) has a strong negative effect on EBPR processes. The reason is that, in an over-aerated process, phosphorus uptake stops because of a gradual depletion of PHB.
5. **Temperature** : Efficiency of EBPR improved as temperature decreases and EBPR performed better at colder temperature (5 - 1C). Better performance of the system was ascribed to reduced competition for substrate in the non-oxic zones, which resulted in an increased PAO population (Erdal *et al*.,2003).

3. PHOSPHORUS REMOVAL USING IRON AND WOOD:

Ferrous ion generated by iron polarization is utilized for phosphorus removal. Ferrous ion combines with phosphate and produces ferrous phosphate (Takahiro *et al*, 2008). Phosphorus and nitrogen removal using iron and wood as electron donar examined in anoxic biological filter reactor. By iron oxidation by hydrogenotrophic denitrification, phosphorus and nitrogen simultaneously removed, and ferrous iron and phosphorus precipitates are formed.



Two moles (190g) of phosphate can be removed by 1.2 mole (74g) of nitrate reduction theoretically.

Disadvantages:

1. The amount of decreased phosphate is much lower than the theoretical value due to the reason that iron precipitated with not only phosphorus but with sulfide and hydroxide also.
2. Iron corrosion occurred quickly under oxic conditions so its obligatory to replace iron frequently.

4. WETLANDS:

An engineered wetland is a wetland that can be changed at will, according to the ever-changing conditions of both climate and the type of waste water; the process conditions and operations can be modified, manipulated, and controlled by the facility management. Basically, it is a container (as small as a bucket or as big as a very large pond) planted with mainly aquatic, but sometimes with terrestrial plants. The roots of plants, especially aquatic macrophytes, both emergent and submerged, work as a giant biological filter that removes organic matter of all kinds (Bashan *et al*, 2004). The macrophyte contributed up to 52% of phosphorus removal by its own growth; the associated organisms and microorganisms removed the rest (Korner and Vermaat, 1998).

Performance of such wetlands in removing pollutants, including phosphorus, can be enhanced by using a reactive sorbent. The sorbent must have a high phosphorus sorption capacity and an adequate hydraulic conductivity. Both the planted and unplanted wetlands showed extremely high phosphate removal (98–100%) during a year of evaluation (Drizo *et al.*, 1997).

ADVANTAGES:

1. The operational and maintenance costs are minimum and affordable even in developing countries.
2. Improvements in plant selection, size and type of substrate, and especially combined with better design for the control of the wetland as an “engineered wetland”, might make the wetland system the method of choice for waste water treatment where land is available and resources are scarce.

DISADVANTAGES:

1. The wetlands are not usually to remove nutrients, such as phosphorus but they do so as these ions are nutrients for plants.
2. The design ions are not flexible, once designed tough to change.
3. Plants often assimilate nutrients so the pollution transferred from one state to the other and the final disposal of such plants is also an issue as otherwise upon degradation of the extract out of all the nutrients stored within them.

5. ONE STAGE ACTIVATED SLUDGE PROCESS(AS):

This is the conventional activated sludge process. The phosphorus is incorporated into the bacteria as cell-building material. The heterotrophic biomass responsible for organic matter degradation has a relatively limited metabolic phosphorus requirement and, in most cases, the biologically available phosphorus present in the waste water exceeds the basic requirements of the heterotrophic biomass (Roques, 1995), which can be derived from the stoichiometry of the biomass, i.e., $\text{C}_{118}\text{H}_{170}\text{O}_{51}\text{N}_{17}\text{P}$.

The approximate C/P ratio is about 100/1. That is, only one unit of phosphorus is incorporated when 100 units of BOD are removed. Consequently, it turns out that only some 10-25% of the phosphorus in the waste water will be removed through this normal growth of cell material (Metcalf and Eddy Inc., 1991). For example, a typical crude sewage entering a waste water treatment plant has about 250 mg/L of BOD in it, while its phosphorus concentration can be anywhere from 5 to 20 mg/L (US Department of the Army, 1978). Given a customary efficiency of no more than 90% BOD removal in a treatment plant, this would indicate the removal of about 237 mg/L of BOD, which would correspond to the removal of some 2.37 mg/L of phosphorus, i.e., one hundredth of the amount of BOD removed, based on the stoichiometric formula given above. Thus, technically, somewhere between 2.6 and 17.6 mg/L of total phosphorus would remain in the effluent stream, depending upon the concentration of total phosphorus in the influent crude sewage (of between 5 and 20 mg/L).

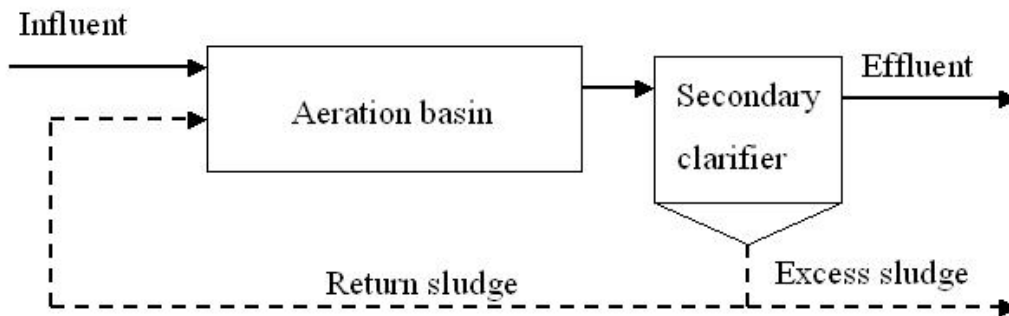


Figure 3. One stage activated sludge process

6. Two Stage Activated sludge process(AO):

The design is a modification of the first design, in which an anoxic tank is added to the aeration tank. Nitrate-rich mixed liquor is recycled from the aeration tank to the anoxic tank, where the collection of organic materials in the influent can serve as hydrogen donors for the denitrification of the nitrates. As a result, part of the organic matter is consumed and nitrate is converted to nitrogen gas, with release to the atmosphere. The mixed liquor is then aerated in the aeration tank, so that the remaining organic matter and ammonia are oxidized. It was found, however, that good phosphorus removal can also be achieved in this process, although such performance is strongly affected by the nitrate concentration in the system, with higher values tending to inhibit phosphorus removal.

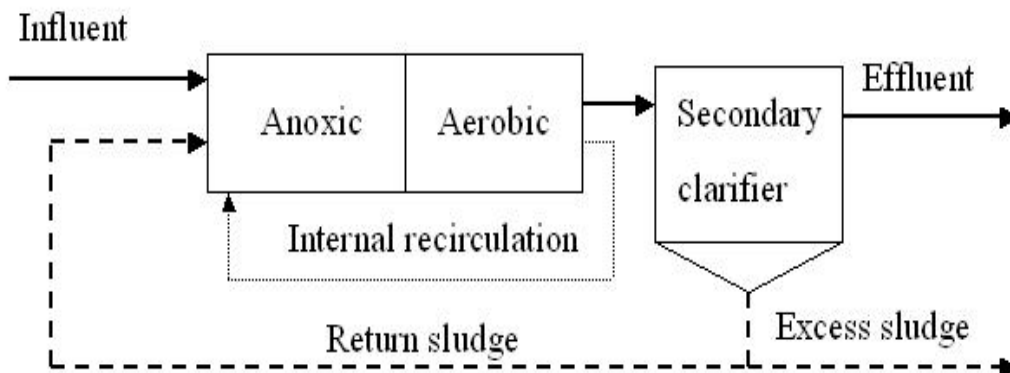


Figure 4. Two stage activated sludge process.

7. THREE-STAGE ACTIVATED SLUDGE PROCESS (AAO):

In this more advanced process design, the goal is to try and culture, preferentially, a form of bacteria known broadly as Phosphate Accumulating Organisms (PAOs), which have the capacity to incorporate more phosphorus into their cell material than the normal basic requirements. For this reason, i.e., that the incorporation of so much phosphorus is not necessary for growth, the behavior of the PAO bacteria is termed “luxury uptake of phosphorus”. Figuratively, the phenomenon can be compared to the “starving man at the banquet”. In the AAO process design, the PAO organisms, having been starved of food in the clarifier (so to speak), are returned into the presence of a fresh supply of phosphorus at the head of the treatment works. The organisms take up more phosphorus than they normally require for their growth and store the excess phosphate until they require it, when exposed again to conditions of starvation.

In the additional anaerobic compartment organisms in the waste form anaerobic byproducts of fermentation, such as succinates, volatile fatty acids (VFAs), and acetates. The VFAs are further converted to poly-hydroxyalkanoates (PHA) with glycogen as an NADH source and poly-P as an energy source. During this process glycogen is consumed and phosphate is released into the liquid stream. Subsequently, in the aerobic compartment, the PAOs take the anaerobic byproducts and reincorporate them into their cellular material. PHA is consumed, whereas glycogen and poly-P are regenerated. Since phosphorus uptake appears to be slightly greater than the release due to the growth process, more phosphorus is removed from the waste water than would otherwise be the case.

In such luxury uptake processes the net rate of phosphate removal is strongly affected by the BOD concentration in the influent crude sewage. If this is too low, phosphate uptake will decrease accordingly, and the total phosphorus concentration in the effluent may exceed the desired regulatory limit.

Enhanced solid removal and, therefore, enhanced removal of particulate-associated phosphorus, can be attained by the addition of low levels (generally under 5 mg/L) of polymers of high molecular weight to the waste waters. A number of such substances can be used to increase the removal of the fine-grained suspended particulates (to which the phosphorus is attached).

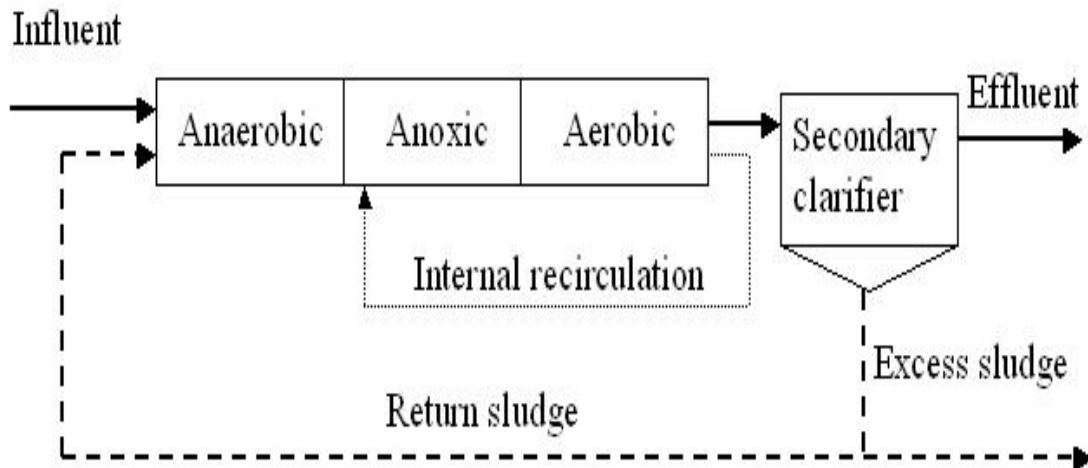


Figure 5. Three-Stage Activated Sludge Process (AAO)

CHEMICAL PROCESSES:

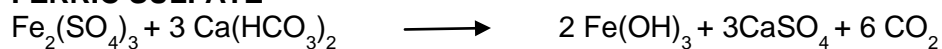
1. IRON PHOSPHORUS PRECIPITATION:

A reaction mixture composed of silica sand, crushed high-content calcium limestone, and several readily available metal oxides were compared. These materials removed greater than 99% of the phosphate from effluent within one hour. Continuous loading of a column composed of silica sand, limestone, and iron / calcium oxide, at representative groundwater flow rates over a four-year period, removed over 90% of phosphates from the water (Baker et al., 1998), showing the long-term potential of these combinations of substances to remove phosphorus.

Adding different concentration of FeCl_2 (20, 40 and 100 mg L^{-1}) to the aeration tank to control filamentous bulking also removed most of the phosphate. The iron salt also was effective in suppressing phosphate release and sulfide production from the wasted sludge by selectively enriching iron-reducing bacteria over sulfate-reducing bacteria. Consequently, iron-oxidizing bacteria out-numbered all the other bacterial populations (Yamamoto-Ikemoto et al., 1998).

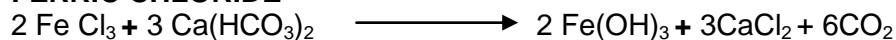
Normally, the main pathway of phosphonate removal is by adsorption onto surfaces. An evaluation of Ca, Cu, Zn, and Fe^{3+} on the adsorption of six phosphonates onto the iron (hydr)oxide, or goethite showed that, when Ca and Zn concentrations were in excess of the phosphonate concentrations (10 mM), considerable increases in adsorption occurred. This is presumably through a ternary surface complex formation and adsorption onto precipitated Zn hydroxides (Nowack and Stone, 1999).

FERRIC SULFATE



Ferric Sulfate + Calcium Bicarbonate Ferric Hydroxide + Calcium Sulfate + Carbon Dioxide

FERRIC CHLORIDE



Ferric Chloride + Calcium Bicarbonate Ferric Hydroxide + Calcium Chloride + Carbon Dioxide

2. ALUM PHOSPHORUS PRECIPITATION:

Aluminum compounds formed during precipitation depend on the type and quantity of organic matter present in the waste water. Solid aluminum species with different surface properties are formed, depending on solution components. Aluminum hydroxide, $\text{Al}(\text{OH})_3$, is a strong adsorption agent for orthophosphate and condensed phosphate. It precipitates organic phosphate only at the low pH of 3.6. The removal of orthophosphate decreased with aging of the alum sludge (Galarneau and Gehr, 1997). A column packed with silica sand, limestone, and activated aluminum oxide removed over 99% of phosphorus, even after two years (Baker et al., 1998). Similarly, even airdried, spent alum sludge adsorbed phosphorus rapidly, with phosphorus reduced 55% in the first 20 minutes after exposure (Huang and Chiswell, 2000). Adsorption by aluminum sulfate can be enhanced by adding organic polyelectrolytes, like tannin, synthetic anionic polyelectrolyte, and clay (Ozacar and Sengil, 2003).

ALUM (ALUMINIUM SULFATE):



Aluminum Sulfate+ Calcium Bicarbonate Hydroxide Aluminum Hydroxide+ Calcium Sulfate + Carbon Dioxide

3. CALCIUM PHOSPHORUS PRECIPITATION:

Phosphorus removal efficiencies in this process ranged from 75% to 85% (Moriyama et al., 2001). Finally, lime was also suggested as a pre-treatment of municipal waste water before the biological process (Marani et al., 1997).

4. MAGNESIUM PHOSPHORUS PRECIPITATION:

Applying $Mg(OH)_2$ to an anaerobic sludge digester resulted in a larger reduction in suspended solids and COD, a higher biogas production rate, and a lower level of phosphate and ammonia concentrations. The required reaction time depends on the initial phosphorus concentration and the dose of $Mg(OH)_2$ (Wu *et al.*, 2001).

PHYSICO CHEMICAL PROCESSES:

The physico chemical process utilizes the solubility of phosphorus-metallic compounds to precipitate the phosphorus down to levels approaching the solubility product of the compounds, and then employs a physical separation process to remove the precipitate from the waste water.

With regards to P removal the most efficient processes are use of metal salts but due to the high cost of the metal salts it becomes an issue for its widespread use. Therefore, number of materials have been tested as sorbents e.g. activated red mud (Pradhan *et al.*, 1998), slag (Lee *et al.*, 1997), sand (Bubba *et al.*, 2003), iron oxide ((Zeng *et al.*, 2004), and granulated ferric oxide (Zeng *et al.*, 2004).

P Removal using Alum Sludge:

At first the disposal, regeneration and reuse of spent alum sludge had then become an important environmental issue. However, Alum sludge having large amount of Al^{3+} ions is highly valuable for phosphorus removal in waste water since the ions enhance processes of adsorption and chemical precipitation (Chu, 2001).

ALUM:



Aluminum Sulfate+ Calcium Bicarbonate Hydroxide Aluminum Hydroxide+ Calcium Sulfate + Carbon Dioxide

1. P removal using dewatered alum sludge:

During the process of sludge treatment including thickening to reduce its volume and then anaerobic digestion to stabilize the sludge, it is believed that P is released to the supernatant (Jardin and Popel, 1994).

In this strategy dewatered alum sludge cakes are used in a fixed bed for P immobilization from the reject water which is the mixture of supernatant of sludge thickening process and the supernatant of the anaerobically digested sludge. Experimental analysis has shown that P concentration is reduced significantly with the use of alum sludge. The strategy using reject water filtration with alum sludge shows that it has P adsorption capacity of 31mg-P/g-sludge under filtration velocity of 1.0m/hr (Yang *et al.*, 2009). So sludge is very beneficial for the use in the WWTPs.

Effect of pH on P-Removal:

A pH increase of 4.3 to 9.0 decreased the P adsorption capacity from 31 to 1.1 mg-P/g-sludge. This is due to the fact that P adsorption onto the alum sludge is coupled with the release of OH^- ions (Yang *et al.*, 2009).

2. P-Removal using liquid alum sludge:

Alum sludge is produced as by product in drinking water treatment plant where aluminum sulfate is used for flocculation of raw water. By many experiments it is proved that alum sludge has significant potential for P-adsorption for reject-water. This strategy can reduce P from 597-675 mg P/L to 0.14-3.20 mg P/L in supernatant of the sewage sludge. (yang *et al.*, 2008).

3. P- removal using spent alum sludge:

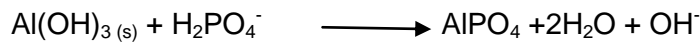
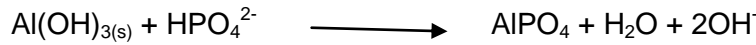
Spent alum sludge is the sludge coming out of drinking water treatment plant. In a study the efficiency of removal of P was compared to the new alum used. Pure alum, iron chloride and iron sulfate were much more efficient than the spent alum sludge. Specially orthophosphorus

was totally removed by alum sludge using 15 mg/L as Al, by alum sludge using 75 mg/L as Al and by FeCl₃.7H₂O using 30 mg/L (Georganats *et al*, 2005).

Aluminium hydroxide is produced during water treatment. Aluminium hydroxide is a substance with high adsorptive capacity and is widely used for the adsorption of P- removal for MWW (Municipal Waste water) (Power *et al*, 1999).

Sample of spent alum sludge is taken from the bottom of the primary clarifiers. The removal of phosphate using aluminium hydroxide is an ion exchange process releasing OH⁻ ions in the solution.

The proposed reaction is as follows:



A comparative study for P- removal to see the results of using fresh alum versus alum sludge has shown that the alum is more effective in the removal of P.

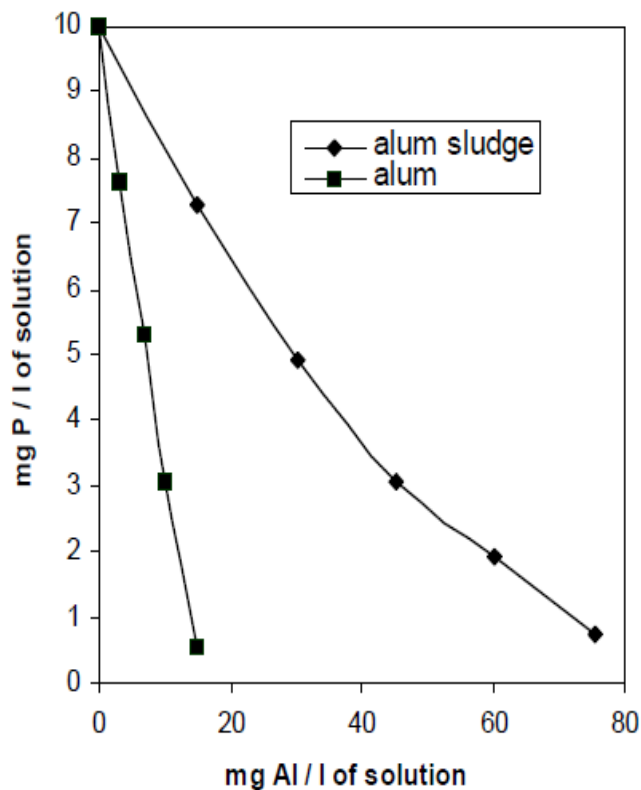


Figure 6. Comparison between alum and fresh alum spent regarding efficiency to remove orthophosphates

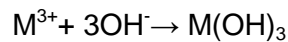
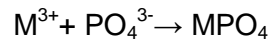
Effect of sludge age:

Sludge demonstrates that there is high rate of decrease of efficiency of removal of P (Georganats *et al*, 2005).

4. Three-stage Activated Sludge with Metal Addition (AAO + M):

While biological luxury uptake may be maximized, in most cases it is not sufficient to reduce the phosphorus content in the effluent below 1 mg/L of total phosphorus (Matsch and Drnevich, 1987). It may be necessary to add metal ions to the waste water in order to remove additional

phosphorus by the physical-chemical means of precipitation. Most commonly, iron as ferric chloride (FeCl_3) and aluminum in the form of aluminum sulfate are used, although phosphorus can also be removed by precipitation with calcium as lime. The precipitation reaction with iron (Fe^{3+}) or aluminum (Al^{3+}) in the trivalent state can be expressed as follows :



The necessary addition of the metal salts can be executed in the primary clarifier, the aeration basin or secondary clarifier, or even in a tertiary clarifier, if available. If the use of metal ions (chemicals) is to be minimized, their addition at the end of the aeration basin may be most cost effective.

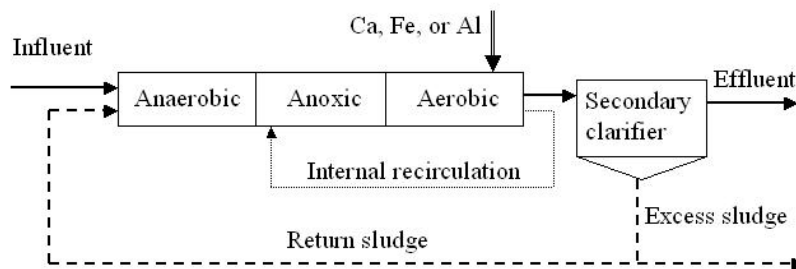


Figure 7. Three-stage Activated Sludge with Metal Addition (AAO + M)

5. Three-stage Activated Sludge with Metal Addition and Tertiary Clarifier (AAO + M + S):

If a more stringent limit for phosphorus (0.5 mg/L) is to be met, a tertiary clarifier or other type of final solid removal device may be needed to further eliminate the solids in the effluent. At such low levels of phosphorus, it is the phosphorus in a particulate form that tends to be dominant. Clarifiers are often used for this purpose, because ;

- They are energy efficient
- Do not require the type of maintenance or attention needed by filtration systems
- Clarifiers are also often less sensitive to changes in hydraulic flows than filter systems and, in terms of backwash or sludge volume,
- They produce 1% - 3% of their through put as sludge, compared with filtration systems, which generally have 5% - 10% of their throughout removed as backwash and rinse waters, with the implied additional costs of treatment and disposal.

Given tertiary sedimentation/clarification, the concentration of total suspended solids in the effluent can be reduced below 5 mg/L, while the concentration of total phosphorus can be reduced to below 0.5 mg/L.

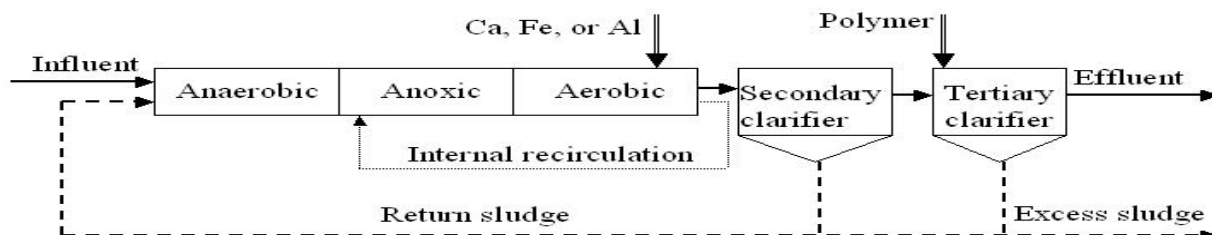


Figure 8. Three-stage Activated Sludge with Metal Addition and Tertiary Clarifier (AAO + M + S)

6. Three-stage Activated Sludge with Metal Addition, Tertiary Clarifier and Filtration(AAO + M + S + F):

Some small particles and their attaching phosphorus may still remain in the effluent, even after the tertiary clarifier. However, if a filter is installed, the solids present in the effluent can be reduced yet further, with thus a concomitant decrease in the effluent total phosphorus concentration. Following tertiary sedimentation and filtration the concentration of total suspended solids can be reduced to 1 mg/L and the total phosphorus concentration to below 0.15 mg/L. In effect, rather than being of significance in its own right, the tertiary clarifier in this fifth design alternative serves as a pretreatment device for the filter, by removing solids and thereby extending the length of the filter run (between backwashing). For this application, the addition of aluminum or calcium salts as precipitants is preferred over that of iron, in order to avoid the growth of filter “slimes”, which make filtration difficult and increase backwash requirements.

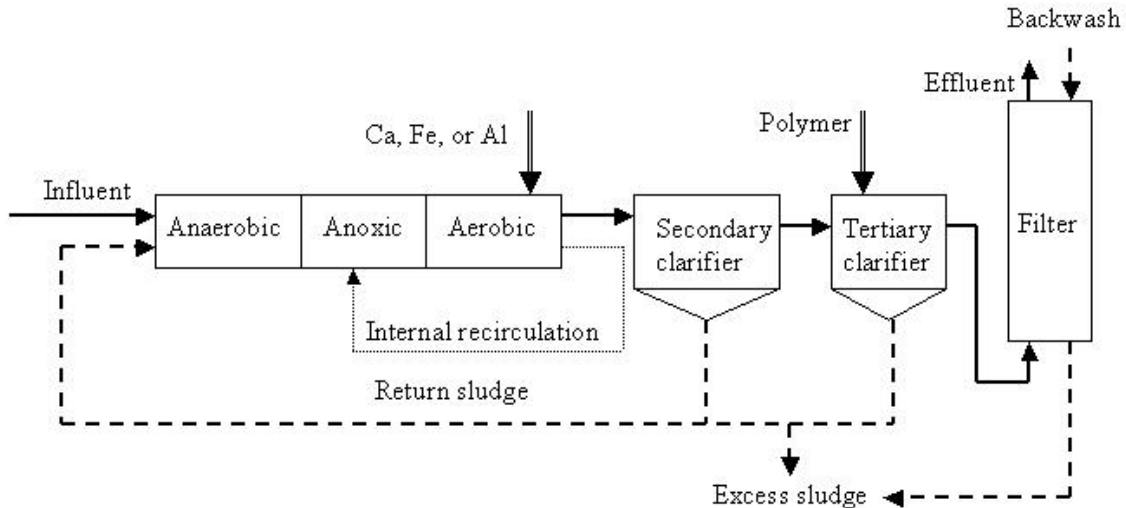


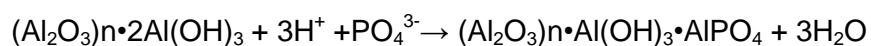
Figure 9. Three-stage Activated Sludge with Metal Addition, Tertiary Clarifier and Filtration (AAO + M + S + F)

7. Three-stage Activated Sludge with Tertiary Clarifier and Activated Aluminum Absorption(AAO + Al + S + C):

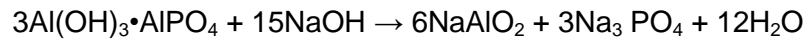
Activated aluminum exhibits a marked attraction for phosphate anions, even in the presence of higher concentrations of sulfate or chloride anions (Donnert *et al*, 1999). This property makes it ideal material for the removal of total phosphorus to very low levels, such as 0.10 mg/L. Several researchers (Donnert *et al*, 1999; Brattebr *et al*, 1985; Hano *et al*, 1997) have studied this process and one pilot plant using this technology has been operated successfully for 500 days. The process has not proven to be popular in practice at full scale as yet, however, we believe, therefore, that the operational cost and higher capital cost may be a deterrent to installation. The operation of the adsorption column consists of three steps (Donnert *et al*, 1999):

- (i) Adsorption of phosphorus onto the granular material;
- (ii) Regeneration of the spent material by means of 0.5 molar NaOH (the material can be reused after rinsing with water);
- (iii) Recovery of phosphorus from the regeneration liquid by $\text{Ca}(\text{OH})_2$. The remaining NaOH solution can be reused for regeneration.

1. **Adsorption of phosphorus** takes place according to the following



2. **Regeneration of the granular material** can be expressed by the reaction



3. **Precipitation of phosphorus** from the regeneration liquid by $\text{Ca}(\text{OH})_2$ as



The two reactions above show that NaOH can be reused after each precipitation process, so that the consumption of NaOH in this process is negligible.

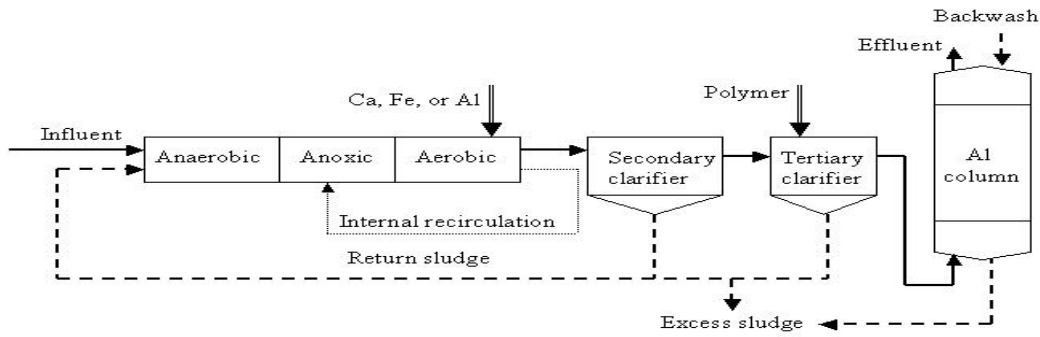


Figure 10. Three-stage Activated Sludge with Tertiary Clarifier and Activated Aluminum Absorption (AAO + Al + S + C)

8. Three-stage Activated Sludge with Metal Addition, Filter, and Membrane Method (AAO + Al + F + UF) :

Utilization of ultrafiltration (UF) membranes is becoming increasingly popular, either following the final clarifier, or in way of the sedimentation process. The membranes are a type of micro-filter that can be selected so that a pore size of less than 0.5 microns can be achieved. The membrane acts as a true surface filter, retaining all particles at the surface, where they can be easily removed by shear forces provided by the flow of the feed solution (Belfort, 1984). In effect, the membrane system is thereby able to achieve one hundred percent removal of suspended solids, resulting in a zero concentration in the effluent, or very close to it. The total phosphorus concentration can be lowered to 0.05 mg/L.

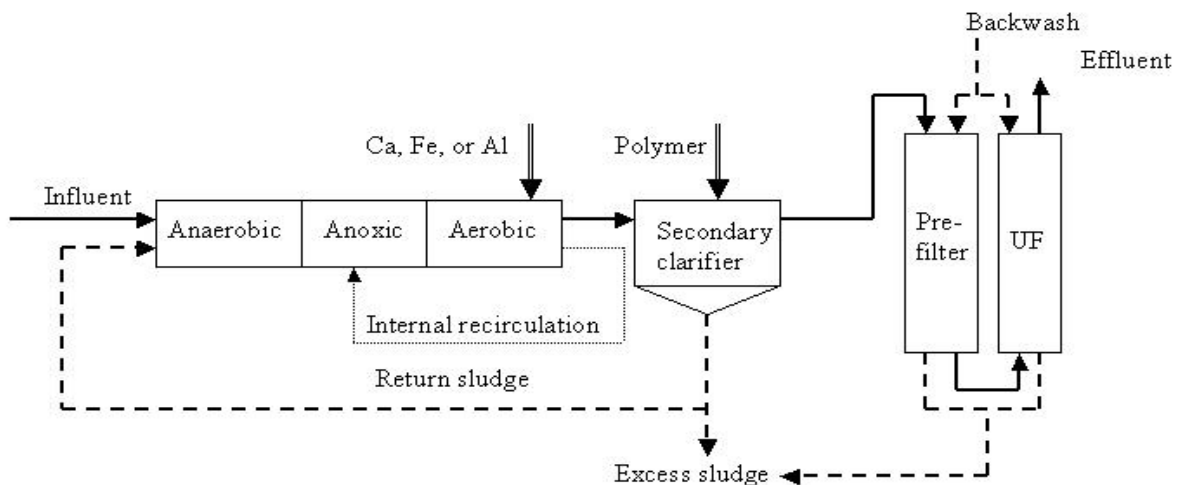


Figure 11. Three-stage Activated Sludge with Metal Addition, Filter, and Membrane Methods (AAO + Al + F + UF)

SUMMARY OF POLLUTANT CONCENTRATIONS FOR THE VARIOUS PROCESS DESIGNS:

To summarize, the estimated effluent qualities of the processes surveyed are given in Table 1.

PROCESS	P REMOVAL %
Effluent of AS	21.8
Effluent of AO	45.1
Effluent of AAO	60.7
Effluent of AAO + M	86.7
Effluent of AAO + M+ S	95.7
Effluent of AAO + M+ S + F	98.1
Effluent of AAO + M+ S + C	98.7
Effluent of AAO + M + F + UF	99.3

Table 1. The estimated effluent quality of the designs

Source: USEPA

PROCESS	ADVANTAGES	DISADVANTAGES
BIOLOGICAL PROCESSES		
Biological Phosphorus Removal (BPR)	Reduced sludge production	Increased complexity
	Improved sludge settle ability and dewatering characteristics	Number of design parameters involved in the processes has also increased
	No need for chemical addition	Additional waste water characteristics required for feasibility of biological phosphorus removal
EBPR (Enhanced Biological Phosphorus Removal)	More removed than conventional BPR	High competition between GAOs and PAOs
	Efficient Bio-P removal can be achieved with MBR systems, in both pre-and post denitrification configurations	
	Sludge is well suited to agricultural reuse	
Wood and Iron	Cheapest Process	Less P removal as Fe oxidized with sulfide also.
		Iron corrodes quickly so necessary to replace quickly
Wetlands	Minimum operation and maintenance cost	Rigid design
	Best option where land and Flora available	Just transform pollution from one state to other
CHEMICAL PROCESSES		
Iron Phosphorus Precipitation	Control filamentous bulking	Increase cost
	Removes greater than 99% of the phosphate from effluent within one hour	Large amount of sludge produced, so difficult to handle
Alum Phosphorus Precipitation	Strong adsorption agent for orthophosphate and condensed phosphate	Precipitates organic phosphate only at the low pH of 3.6
Calcium Phosphorus Precipitation	Removal efficiencies in this process ranged from 75% to 85%	Increase in cost
	Suggested as a pre-treatment of municipal waste water before the biological process	Large amount of sludge produced, so difficult to handle

PHYSICO CHEMICAL PROCESSES		
Cheapest method		Process Highly dependant on Sludge Age
Sludge of drinking water treatment plant handled		Tough handling of resultant sludge
Dewater alum sludge	P adsorption capacity of 31 mg-P/g-sludge	Increase of 4.3 to 9.0 decreased the P adsorption capacity from 31 to 1.1 mg-P/g-sludge
		First the sludge treatment in term of sludge drying is required
		Land requirement increased for the need of drying beds
P-Removal using liquid alum sludge	Reduce P from 597-675 mg P/L to 0.14-3.20 mg P/L	The sludge must have contents of aluminum sulfate

Table 2. Advantages and Disadvantages

COST ESTIMATION:

The details are derived from costs for municipal waste water treatment plants quoted in USEPA, and for water treatment facilities in USEPA, appropriately updated for inflation according to the Engineering News Record (ENR) construction cost index (McGraw-Hill Co., 2004). The cost of the ultrafiltration process is estimated from the research of Drouiche *et al* (2001).

Factor	Component	Estimation Method
Construction Cost	Equipment	Technology specific cost
	Installation	25-55% of equipment cost
	Piping	31-66% of equipment cost
	Instrumentation and Controls	6-30% of equipment cost
Indirect Cost	Engineering	15% of total construction cost
	Contingency	15% of total construction cost

Table 3. Apparent Costs

Source USEPA

OPERATION AND MAINTENANCE COST:

It is apparent that the costs of maintenance, taxes, and insurance are estimated merely as a percentage of the total capital cost. Labor costs are calculated according to the manpower needed and the average salary of common labor.

Factor	Estimation
Maintenance	4% of total capital cost
Taxes and insurance	2% of total capital cost
Labour	21.28 \$ /hr
Electricity	0.0499\$ / KWH
Chemicals	Al ₂ (SO ₄) ₃ .12H ₂ O 80\$/ton
	Ca(OH) ₂ 80.8\$ /ton
	Polymers 3780\$ / ton
Residual management	Disposal cost 0.27\$/Kg of sludge 1.24\$/kg of chemical + biological sludge

Table 4. O & M costs

Source USEPA

THE TOTAL ECONOMIC COST:

Process	Flow	Maintenance	Taxes and insurance	Labor	Electricity	Chemicals	Residuals management	Total O&M cost	Total Capital Cost (2004) \$ * 10 ⁶	Total economic Cost \$ * 10 ⁶
AS	10.0	1.58	0.79	1.11	0.32	0	0.33	4.13	39.53	43.66
	50.0	5.12	2.56	3.11	1.13	0	1.65	13.57	127.99	141.56
	100.0	8.49	4.25	5.16	1.95	0	3.31	23.16	212.28	235.44
AO	10.0	1.88	0.94	1.24	0.45	0	0.34	4.85	46.84	51.69
	50.0	5.98	2.99	3.45	1.60	0	1.71	15.73	149.45	165.18
	100.0	9.93	4.97	5.76	2.77	0	3.42	26.85	248.29	275.14
AAO	10.0	2.18	1.09	1.33	0.45	0	0.38	5.43	54.52	59.95
	50.0	7.29	3.65	3.85	1.62	0	1.88	18.29	182.28	200.57
	100.0	12.26	6.13	6.61	2.8	0	3.77	31.57	306.55	338.12
AAO + AI	10.0	2.19	1.09	1.33	0.45	0.05	1.99	7.1	54.65	61.75
	50.0	7.3	3.65	3.85	1.62	0.24	9.93	26.59	182.54	209.13
	100.0	12.28	6.14	6.61	2.81	0.48	19.85	48.17	306.98	355.15
AAO + AI + S	10.0	2.24	1.12	1.35	0.46	0.07	2.26	7.5	56.03	63.53
	50.0	7.54	3.77	3.89	1.62	0.37	11.29	28.48	188.59	217.07
	100.0	12.76	6.38	6.69	2.81	0.75	22.57	51.96	318.94	370.9
AAo + AI + S + F	10.0	2.35	1.17	1.42	0.48	0.07	2.33	7.82	58.72	66.54
	50.0	8.26	4.13	4.14	1.76	0.37	11.64	30.3	206.39	236.69
	100.0	13.78	6.89	7.26	3.08	0.75	23.27	55.03	344.41	399.44
AAO + AI + S + C	10.0	2.64	1.32	1.53	0.51	0.08	2.37	8.44	65.88	74.32
	50.0	9.51	4.76	4.21	1.87	0.41	11.85	32.61	237.87	270.48
	100.0	16.44	8.22	7.13	3.01	0.81	23.7	59.58	410.95	470.53
AAO + AI + F + UF	10.0	2.91	1.46	1.50	0.62	0.19	2.5	9.18	72.79	81.97
	50.0	11.09	5.55	4.25	2.46	0.95	12.5	36.80	277.31	314.11
	100.0	19.45	9.72	7.39	4.49	1.90	25	67.95	486.18	554.13

Table 5. Total Economic Cost

Source USEPA

(Total Economic Cost = Total Capital cost + total O&M Cost)

REFERENCES:

- M. P. Thomas, 2008, the secret of achieving reliable biological phosphorus removal, water science and technology, volume 58, Issue 6, Page No. 1321-1236
- D. A. Georganatas and H. P. Grigoropouou, 2005, Phosphorus removal from synthetic and municipal waste water using spent alum sludge, water science and technology, volume 52, Issue 10, Page No. 525-532
- Y. Yang, Y. Q. Zhao, A. O. Babatunde and P. Kearney, 2009, Two strategies for removal of reject water of municipal waste water treatment plant using alum sludge, water science and technology, volume 60, Issue 12, Page No. 3181-3188
- Y. Yang, D. Tomlinson, S. Kennedy and Y. Q. Zhao, 2006, Dewatered alum sludge: a potential absorbant for phosphorus removal, water science and technology, volume 54, Issue 5, Page No. 207-213
- Takahiro Yamashita and Ryoko Yamamoto-Ikemoto, 2008, Phosphate removal and sulfate reduction in a denitrification reactor packed with iron and wood as electron donar, water science and technology, volume 58, Issue 7, Page No. 1405-1413
- Peter F. Storm, 2006, Technologies to remove phosphorus from waste water, Rutgers University.
- F. Jiang, M.B. Beck, R. G. Cummings, K. Rowlers and D. Russell, 2004 , Estimation of Cost of Phosphorus Removal in waste water treatment facilities: Construction *De Novo*, Water policy paper no. 2004-010.
- S. M. Scherrenberg, A. F. van Nieuwenhuijzen, H.W.H. Menkveld, J. J. M. den Elzen and J. H. J. M. van der Graaf, 2008, Innovative phosphorus distribution method to

achieve advanced chemical phosphorus removal, water science and technology, volume 58, Issue 9, Page No. 1727-1733

- Luz E. de Bashan and Yoav Bashan, 2004, Recent advances in removing phosphorus from waste water and its use as fertilizer, Water Research 38, 4222-4246
- Y. Cao, C. M. Ang, K.C. Chua, F.W. Woo, H. Chi, B. Bhawna, C. T. Chong, N. Ganesan, K. E. Ooi and Y. L. Wah, 2009, Enhanced biological phosphorus removal in the retrofitting from an anoxic selector to an anaerobic selector in a full scale activated sludge process in Singapore, water science and technology, volume 59, Issue 5, Page No. 857-864
- Dwight Houweling, Yves Comeau, Ime Takacs and Peter Dold, 2010, Uncertainty and variability in EBPR stoichiometry: consequences for process modeling and optimization, water science and technology, volume 61, Issue 7, Page No. 1793-1800

(Drawing No. 3)