www.kosmospublishers.com
contact@kosmospublishers.com
DOI: 10.37722/ESPRAM.2022101

Research Article Environmental Science, Pollution Research and Management ESPRM-116
ISSN 2693-7530

A Review on Low-Cost Phosphorous Removal Techniques from Domestic and Industrial Waste Water

Rosalin Das*

Fakir Mohan University, Balasore, Odisha, India-756089

Received Date: January 23, 2022; **Accepted Date:** January 29, 2022; **Published Date:** February 03, 2022;

***Corresponding author:** Rosalin Das, Fakir Mohan University, Balasore, Odisha, India-756089.
Email: rosalindas.geology@gmail.com

Abstract

This review article comprehends the efficient techniques of removal of Phosphorous from domestic and industrial waste water which are cost effective. The removal of excess of phosphorous during wastewater treatment is vital for ensuring and protecting the ecosystem. A major source of Phosphorus is from agricultural fertilizer dissolution, manure and organic wastes from sewages and industrial effluents. The excess of the element in water, speed up eutrophication. Hence controlling phosphorous concentration from industrial and municipal waste water prevents eutrophication of surface water. The raw waste water phosphorus level is 200-300mg/l and discharge limit are 15mg/l. Excess concentration of phosphorous causes many water quality problems including increased purification costs, decreased recreational, loss of livestock and the possible lethal effect of algal toxins on drinking water. The removal of P from wastewater can be performed using physico-chemical methods, biological and Enhanced Biological Phosphorus Removal (EBPR) method, and/or combinations of both. The Physico chemical method deals with precipitation, coagulation, and flocculation. The most common chemical P-removal options involve dosing metal salts to either pre-treated influent or to the conventional activated sludge (CAS) reactors. P removal rates are typically proportional to the mass of chemical added. The chemical adsorptive media are manufactured from natural products, such as apatite, bauxite, lime stone, industrial wastes such as, fly ash, steel slud or ochre. Phosphate removal rate found to be 91% when Polonite is used to treat municipal wastewater over a period of 1 year with a P-sorption capacity of 120 g/kg. Other chemical precipitation of soluble phosphorous, use metal salts i.e., aluminium based chemical product e.g., Alum, iron based chemical products e.g., ferric chloride. The Enhanced biological phosphorus removal (EBPR) technique is the modification of biological process that incorporates phosphorus in the cellular substance. In this process P can be removed without addition of chemicals. In EBPR technique, Polyphosphate-accumulating organisms (PAO) such as Candidatus Accumulibacter and Tetrasphaera were both important in all plants and contained together 24–70% of the total Phosphorus. The contribution of Tetrasphaera to the total P-removal was higher than that of Candidatus Accumulibacter. This paper deals with the cost effective and environmentally sustainable techniques of phosphorous removal from small scale domestic and industrial wastewater.

Keywords: Biological method; EBPR techniques; Phosphorous removal; Physico-chemical; Waste water

Introduction

With the growing population the demand for Phosphorus is increasing strongly along with the necessities of fertiliser for agriculture. Whereas global P reserves are limited, present in only few countries, and getting increasingly more difficult to access (Cordell, D. et. al, 2009, 2011). Given the vital importance of P as a fertilizer in food production, its global scarcity is likely to become one of the greatest challenges of the 21st century. Rocks are the main abiotic reservoir of phosphates, i.e., phosphorite or rock phosphate contains 15 to 20% phosphate bearing minerals. Along with Igneous and metamorphic rocks, the major source of phosphate bearing mineral is fluorapatite ($Ca_5(PO_4)_3F$) or hydroxyapatite ($Ca_5(PO_4)_3OH$). On the other hand, the anthropogenic release of P is a major threat to the environment as it is a main driver of eutrophication, with major contributions from agriculture and untreated Sewage disposal and liquid urban waste (domestic and industrial) (Conley, DJ. et al., 2009). Efficient removal of P from wastewater can prevent eutrophication in sensitive water bodies and the removed P can be applied as fertilizer (Blackall, L.L. et al., 2002).

The increased concentration of phosphorus develops the algae blooms in surface water bodies. 70% to 90% of phosphorus in drain liquids is either orthophosphate or polyphosphates. In order to prevent negative impact of phosphorus on the environment the limits on total P discharges have set to 1 mg/l or 2 mg/l. The lower limit less than 0.5 mg/l concentration inhibits or even blocks the growth of algae. Waste water coming from the detergent plants are a significant source of phosphorus in nearby river water, so restriction in use of phosphorus in detergent can reduce its impact. Also, reduction in amount of sodium tripolyphosphate (STPP) used in detergent builders and as an alternative non-phosphate-based builders, such as Zeolite can be switched to.

All polyphosphate forms gradually hydrolyze in aqueous solution and revert to the orthophosphate form (Mostafa, 2012). According to Prigent (2012), orthophosphate (PO_4-P) is the most abundant form in domestic wastewater. It represents 60–85% of total phosphorus due to the hydrolysis of polyphosphates and organic phosphates.

This paper presents a compendium of techniques for removal of phosphorus from waste water.

Phosphates can be removed by physico chemical methods and biological method or by modifying the biological process that incorporates phosphorus in the cellular substance. Combinations of these two methods and some other specific technologies are also used for phosphorus removal. Certain widely used methods are cited below.

Physico chemical method deals with precipitation, coagulation, and flocculation. Most processes include precipitation, sorption and/or ion exchange mechanisms.

Chemical Precipitation

It is one of the most convenient methods that causes dissolved phosphorus to settle out of solution. The insoluble phosphorus containing sediments can be settled, centrifuged, filtered, and separated from the liquid by adding agents known as coagulant by other methods called precipitates. This causes small, suspended matter to form bigger aggregates. After precipitation the liquid part is called supernate. During settling, the precipitate catches ions and particles from solution, which increases efficiency of the method. Compounds of iron, aluminium and calcium are chemicals primarily used in P precipitation such as, ferric chloride, ferrous sulphate, aluminium sulphate (alum), and lime. Further, P removal rates are typically proportional to the mass of chemical added, which impacts the amount of extra solids produced; therefore, there are intrinsic cost-benefits to the amount of salt used and the method of solids separation used. P effluent concentrations of 1 mg/L can be achieved by conventional gravity settling (Burton et al., 2014).

Research suggests that due to several bireactions, the amount of salt required to achieve the desired P removal rate is greater than the stoichiometric ratio and up to double (Whalley et al., 2013) In case of use of iron or aluminium salts in phosphorus removal, insoluble metal phosphates are produced. The formation of these compounds is pH-dependent where pH level strongly affects the degree of insolubility of metal phosphates. If lime is used, special conditions should be fulfilled to ensure the reaction between excess calcium ions and phosphate. This could be done if pH of the solution is not less than 10, so it is important to add sufficient amount of lime. In this process excess amount of sludge are produced, which must be transported to regional sludge management facilities and the environmental cost-benefit of such activities must be analysed. One benefit of extra sludge production is the opportunity for biogas production through anaerobic digestion. It has been suggested that the use of chemical-rich sludge may limit biogas productivity (Parsons and Smith, 2008).

Coagulation and flocculation

This method allows removal of the suspended compounds in colloidal form from wastewater. In the first case polyvalent ions like Fe^{3+} or Al^{3+} are used, while in the second the long-chain polymers are added as the flocculation agents. Polymers' long-chain molecules can be either positively (cationic) or negatively (anionic) charged or be neutral (non-ionic). Since in wastewater treatment the interactions usually take place between ions and charged particles, the electrical qualities of polymers are very useful. As use of coagulants generates secondary pollutions and due to high cost of reagents, the chemical methods are usually avoided.

Adsorption method

In this method phosphorus is absorbed by the sorbent surface. The application of sorption technology is very effective due to its high efficiency of adsorption and does not produce sludge (Ashekuzzaman, S. and Jiang, 2014). The P removal sorbent mainly have high porosity, high internal surfaces and high content of Al, Fe, Ca, and Mg or have locations suitable for P anion exchange (Jeon, D.J. and Yeom, S.H., 2009). Sorbent can be manufactured of granulated aluminium oxide, activated aluminium oxide, and aluminium sulphate, hydrated titanium dioxide, activated with oxides of Group 3 and Group 4 metals of the periodic system (Zhou, Y.F et al., 2010) with components coated on fibre materials; dolomite proved to have high adsorption ability respective to impurities of phosphorus compounds (with more than 95% of phosphorus removed). Absorptive media are manufactured from either, natural products (e.g., apatite, bauxite or limestone), industrial waste products (e.g., fly-ash, ochre or steel slag) or man-made products (e.g., Filtralite TM). Some of the sorbents used in the research for P removal include clay minerals (Omar, M. et al., 2016), zeolites (Jiang, C. et al., 2013), Al oxides (Lee, G. et al., 2019), limestone (Mateus, D.M et al., 2012), fly ash (Li, S. et al., 2017), steel slag (Lan, Y. et al., 2006) and biochar (Dai, L. et al., 2017) About 25% of phosphorus in the waste streams can be removed by immobilization on a solid sorbent (Mehta, C.M. et al., 2015). There are several commercially available products of which the most widely studied is Polonite. Renman and Renman (2010) report a phosphate removal rate of 91% when using Polonite to treat municipal wastewater over 1 year with a P-sorption capacity of 120 g/kg. Magnetite has a great potential for phosphorus removal because of its high efficiency, especially at low concentrations of input phosphorus. It was also found that the contact time and sedimentation time of the method is relatively small. Recovering of magnetite is also possible but the process of reuse needs additional renovation stage.

Ion Exchange method

In this method the ion exchange resins are an important group of ion exchangers that are used to remove cationic and anionic pollutants from wastewater. Anion exchange resins with positive charge are used to remove phosphate from aqueous solution. (Blaney, L.M, 2007; Johir, M. et al., 2011; Awual, R. et al., 2011).

The performance of ion exchanger is governed upon the valence and weight of the ion in use. The more advance research has improved efficiency through pre-treatment of ion exchange media, for example to improve selectivity for phosphorus ions, the ferric oxide and aluminium hydroxide are used which results 80 to 90% of P-removal. (Martin et al., 2009; Seo et al., 2013). Ion exchange systems have the advantage of delivering P-recovery through post-treatment of the sorption media (Martin et al., 2009). High P removal is achieved in small scale at laboratory level, whereas at full scale the implementation of this technique is expensive for the recovery of P and the sensitivity of some media to pH conditions (Zhao and Sengupta, 1998; Sendrowski and Boyer, 2013). However, the research of Seo et al., (2013) suggested that certain ion exchange materials offer potential, with the addition of a single chemical solution required for regeneration of the media.

Magnetic Field method

In the method to remove phosphates in a magnetic field, phosphates are bound with a reagent in insoluble compounds, whereupon magnetic material is added to create a magnetic field that isolates phosphate-containing sediment.

Biological method

The biological method of phosphorus removal is the first step in the Enhanced biological phosphorus removal (EBPR) wastewater treatment plant where concentration of organic compound, potential inhibitor and other pollutants are maximum in comparison to other wastewater treatment process**.** It is considered to be a cost effective and environmentally sustainable alternative to chemical treatment (Acevedo et al., 2012; Nguyen et al., 2013).

Enhanced biological phosphorus removal (EBPR) is the universally adapted technique of removal of phosphorous by modifying the biological process that incorporates phosphorus in the cellular substance. In this process P can be removed without addition of chemicals. (Blackall LL, et al., 2002; Melia PM, et al., 2017). The strong sides of the method are minimal sludge production and moderate operational cost. Compared to chemical precipitation, the main advantage of EBPR is the absence of metal ions from coagulant in the sludge. EBPR is a process held in the environment that force biomass to consume more phosphorus than generally is needed for growth in the normal conditions (Metcalf and Eddy, 2014). EBPR exploits the capability of certain microorganisms, termed polyphosphate (poly-P) accumulating organisms (PAO), to store large quantities of orthophosphate (ortho-P) intracellularly as poly-P. This P-enriched biomass can be removed from the treated wastewater as surplus sludge and used directly as fertilizer or for recovery of Phosphorus. During EBPR process activated sludge should adapt to the changing anaerobic-aerobic conditions.

Under anaerobic conditions, PAO use energy gained from hydrolysis of poly-P to take up organic substrate (volatile fatty acids (VFAs)) and convert it to storage compounds polyhydroxyalkanoates (PHAs), while under subsequent aerobic conditions, they accumulate large amounts of ortho-P released from bacterial cells during degradation of poly-P and respire the previously stored organic substrate. By removing biomass after the aerobic phase, poly-P can be harvested in wastewater treatment plants (WWTPs). Presence of carbon and phosphate sources at the same time under aerobic conditions has negative effects on phosphorus uptake by microorganisms.

In wastewater, several substances can be used which inhibit biological phosphorus removal process—pharmaceuticals (doxycycline, tetracycline, diclofenac), heavy metals (copper, tin, silver, chromium), salts, H_2S and nanomaterials.

For EPBR the suitable condition requisite for PAO includes,

I. The presence of GAO (Glycogen Accumulating Organisms) metabolizes volatile fatty acids (VFAs) and other carbon compounds which is the common cause of poor performance in EBPR system (Oehmen et al., 2007).
II. Accumulibacter (Candidatus Accumulibacter phosphatis) are considered the prevalent PAO in effective EBPR systems (Zeng et al., 2003; López-Vázquez et al., 2008).
III. The tetrasphera-related Acintobacteria sp. have also been found in high abundance in well performing P-removal systems and proven to carry out luxury P uptake (Oehmen et al., 2007; Nguyen et al., 2011). However, it is known that

they generally accumulate more complex carbon sources, such as amino acids and proteins under anaerobic conditions as an unidentified substance (Günther et al., 2009).

Candidatus Accumulibacter and Tetrasphaera were both important in all plants and contained together 24–70% of the total Phosphorus. The contribution of Tetrasphaera to the total P-removal was higher than that of Candidatus Accumulibacter (Fernando Eustace Y. et al., 2019). Recent application of EBPR incorporates membrane bioreactors (MBR), granular sludge reactors, and Sequencing batch biofilm reactors (SBRs). Inclusion of EBPR in MBRs, whether SBRs or continuous-flow, has proven successful in achieving high levels of P-removal from municipal wastewater. MBRs offer several advantages including the retention of solids within the reactor, which results in a high mixed liquor suspended solids concentrations without the need for a large system footprint (Ng et al., 2000).

Infiltration-percolation Techniques

According to Mahmoud Bali & Moncef Gueddari (2019) intermittent infiltration–percolation process is capable of oxidizing and decontaminating wastewater. He tried this method to evaluate the capacity of intermittent sand filter in the elimination of orthophosphate from secondary wastewater effluents. This technique can be used as a tertiary treatment for suspended solids, organic matter, and nitrogen. However, it is less efficient concerning the reduction of orthophosphate.

Conclusion

Increasing demand of phosphorus for fertilizer purpose and the requirement of removal of P due to the anthropogenic activities, demands the innovative technique of removal of Phosphorus efficiently from the wastewater in small as well as large scale. Achieving high level of P removal through physico-chemical systems is often expensive. There is not a single fit to all proven technology for P-removal. The P-removal technology can be achieved in expense of higher energy consumption, increased operational complexity and excess maintenance. In small scale domestic wastewater treatment system, application of different physico- chemical methods may attain effective and sustainable. Enhanced biological phosphorus removal (EBPR) is a widely used method to decrease P concentration in a full-scale wastewater treatment plant modifying the biological process that incorporates phosphorus in the cellular substance. It is a cost effective and environmentally sustainable alternative to chemical method. The strong sides of the method are minimal sludge production and moderate operational cost. In comparison to chemical precipitation, the main advantage of EBPR is the absence of metal ions from coagulant in the sludge. In alternate aerobic and anaerobic condition, the Candidatus Accumulibacter and Tetrasphaera are considered as the prevalent PAO in effective EBPR system. The ecological sensitivity of remote water sources and for efficient removal of P from domestic and industrial wastewater at small or large scale, further research, especially reliable technologies that require minimal maintenance are to be invented.

References

1. Acevedo B et al. (2012) Metabolic shift of polyphosphate-accumulating organisms with different levels of polyphosphate storage. Water Res, 46:1889-1900.
2. Ashekuzzaman S et al. (2014) Study on the sorption–desorption–regeneration performance of Ca-, Mg- and CaMg-based layered double hydroxides for removing phosphate from water. Chem. Eng. J, 246:97-105.
3. Awual R et al. (2011) A weak-base fibrous anion exchanger effective for rapid phosphate removal from water. J. Hazard. Mater, 188164-171.
4. Blackall LL et al. (2002) A review and update of the microbiology of enhanced biological phosphorus removal in wastewater treatment plants. A Van Leeuw J Microb, 81:681-91.
5. Blaney LM et al. (2007) Hybrid anion exchanger for trace phosphate removal from water and wastewater. Water Res, 41:1603-1613.
6. Burton FL et al. (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th Edn. New York, NY: McGraw-Hill.
7. Conley DJ et al (2009) Controlling eutrophication: nitrogen and phosphorus. Science, 323:1014-5.
8. Cordell D, Drangert JO, White S (2009) The story of phosphorus: global food security and food for thought. Glob Environ Chang, 19:292-305.
9. Cordell D et al. (2011) Towards global phosphorus security: a systems framework for phosphorus recovery and reuse options. Chemosphere, 84:747-58.
10. Dai L et al. (2017) Calcium-rich biochar from the pyrolysis of crab shell for phosphorus removal. J. Environ. Manag, 198:70-74.
11. Fernando Eustace Y et al. (2019) Resolving the individual contribution of key microbial populations to enhanced biological phosphorus removal with Raman–FISH, The ISME Journal, 13:1933-1946.
12. Gunther S et al. (2009) Dynamics of polyphosphate-accumulating bacteria in wastewater treatment plant microbial communities detected via DAPI (4′, 6′-diamidino-2- phenylindole) and tetracycline labeling. Appl. Environ. Microbiol, 75:2111-2121.
13. Jeon DJ et al. (2009) Recycling wasted biomaterial, crab shells, as an adsorbent for the removal of high concentration of phosphate. Bioresour Technol, 100:2646-2649.
14. Jiang C et al. (2013) Adsorptive removal of phosphorus from aqueous solution using sponge iron and zeolite. J. Colloid Interface Sci, 402:246-252.
15. Johir M et al. (2011) A. Removal and recovery of nutrients by ion exchange from high rate membrane bio-reactor (MBR) effluent. Desalination, 275:197-202.
16. Lan Y et al. (2006) Phosphorus removal using steel slag. Acta Met. Sin, 19:449-454.

17. Lee G et al. (2019) Efficient phosphorus removal from MBR effluent with heated aluminum oxide particles (HAOPs). Water Res, 159:274-282.
18. Li S et al. (2017) Characterization of fly ash ceramic pellet for phosphorus removal. J. Environ. Manag, 189:67-74.
19. Lopez et al. (2008) Factors affecting the microbial populations at full-scale enhanced biological phosphorus removal (EBPR) wastewater treatment plants in The Netherlands. Water Res. 42:2349-2360.
20. Mahmoud Bali, Moncef Gueddari (2019) Removal of phosphorus from secondary effluents using infiltration–percolation process. Applied Water Science, 9.
21. Martin BD et al. (2009) Removal and recovery of phosphate from municipal wastewaters using a polymeric anion exchanger bound with hydrated ferric oxide nanoparticles. Water Sci. Technol. 60:2637-45.
22. Mateus DM et al. (2012) Fragmented limestone wastes as a constructed wetland substrate for phosphorus removal. Ecol. Eng, 41:65-69.
23. Mehta CM et al. (2015) Technologies to Recover Nutrients from Waste Streams: A Critical Review. Crit. Rev. Environ. Sci. Technol, 45:385-427.
24. Melia PM et al. (2017) Trends in the recovery of phosphorus in bioavailable forms from wastewater. Chemosphere, 186:381-95.
25. Metcalf, Eddy et al. (2014) Wastewater engineering: treatment and resource recovery, Fifth Edit. ed. McGraw Hill Education.
26. Mostafa AH (2012) Effect of cement kiln dust addition on activated sludge process without primary settling for reuse applications. HBRC J, 8:19-33.
27. Ng WJ (2000) Study on a sequencing batch membrane bioreactor for wastewater treatment. Water Sci. Technol, 41:227-234.
28. Ngugen TT et al. (2011) High diversity and abundance of putative polyphosphate-accumulating Tetrasphaera-related bacteria in activated sludge systems. FEMS Microbiol. Ecol, 76:256-267.
29. Ngugen TT et al. (2013) Pilot scale study on a new membrane bioreactor hybrid system in municipal wastewater treatment. Bioresour. Technol, 141:8-12.
30. Oehmen A et al. (2007) Advances in enhanced biological phosphorus removal: from micro to macro scale. Water Res, 41:2271-2300.
31. Omar M et al. (2016) Modification of the swelling characteristics and phosphorus retention of bentonite clay using alum. Soils Found, 56:861-868.
32. Parsons SA, Smith JA (2008) Phosphorus removal and recovery from municipal wastewaters. Elements, 4: 109-112.
33. Prigent S (2012) Optimisation du traitement de l'azote et du phosphore des eaux usées domestiques adapté aux filtres plantés de roseaux. Doct. Thesis, School of Mines of Nantes, University of Nantes Angers Le Mans, 230.
34. Renman A, Renman G (2010) Long term Phosphate removal by the calcium-silicate material Polonite in wastewater filtration systems. Chemosphere, 79:659-664.
35. Sendrowski A, Boyer TH (2013) Phosphate removal from urine using hybrid anion exchange resin. Desalination, 322:104-112.
36. Seo YI, Hong KH, Kim SH, Chang D, Lee KH et al. (2013) Phosphorus removal from wastewater by ionic exchange using a surface-modified Al alloy filter. J. Ind. Eng. Chem, 19:744-747.
37. Whalley M (2013) Meeting ultra-low effluent phosphorus in small, cold-climate WWTFs. Proc. Water Environ. Fed. 2013:213-217.
38. Zeng L et al. (2004) Adsorptive removal of phosphate from aqueous solutions using iron oxide tailings. Water Res, 38:1318-1326.
39. Zhao D, Sengupta AK (1998) Ultimate removal of phosphate from wastewater using a new class of polymeric ion exchangers. Water Res, 32:1613-1625.
40. Zhou YF et al. (2010) Sorption of Heavy Metals by Inorganic and Organic Components of Solid Wastes: Significance to Use of Wastes as Low-Cost Adsorbents and Immobilizing Agents. Crit. Rev. Environ. Sci. Technol, 40:909-977.

Citation: *Das R (2022) A review on low-cost phosphorous removal techniques from domestic and industrial waste water. Enviro Sci Poll Res and Mang: ESPRM-116.*