Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

A Comprehensive Review on Inhibitory Factor of Enhanced Biological Phosphorus Removal Process.

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Abstract

The needs of human life and their health has bought a sever changes in the treatment process of wastewater treatment. The presence of excess nutrient in natural streams and treated wastewater might pose potential harm to the ecosystem. Global concern about the removal of phosphorus from contaminated water due to the harmful consequences that excess phosphorus has on the environment. When present in excess in aquatic systems, phosphorus can cause poor water quality and the eutrophication that results in the death of aquatic life. Two of the primary sources that contribute to the buildup of phosphorus in wastewater are industry and agriculture. Several methods have been developed to extract phosphorus from wastewater in an effort to stop the negative environmental effects of excess phosphorus. A tried-and-true method for removing phosphorus from wastewater is enhanced biological phosphorus removal (EBPR). It is regarded as a more affordable and environmentally friendly treatment option than chemical ones.

Keywords: phosphorus. Biological reaction, nutrient, eutrophication, Carbon.

1. Introduction

The hindrance of eutrophication can be effectively done by phosphorus removal in the wastewater using a closed water system. If the content of phosphorus is high, it leads to different water quality problems like recreation values will be low, possibility of algal effects, loss in live-stock and treatment cost will be increased (Yeoman et al., 1988). Generally, removal phosphate from the wastewater is attained by chemical precipitation. Chemical precipitation is a costly and also results in increase in sludge production but the main advantage of this method is its relatively mere process (Rashmi et al.,2019) . During this process the sludge increase was up to 30% of volume and also the sludge was contaminated with high range of heavy metals. Hence it is necessary for alternative of chemical precipitation for the removal of phosphorus.

When compared to chemical phosphorus removal, one option that offers clear advantages is biological phosphate removal. The availability of phosphates and the lack of other undesirable compounds make the sludge produced by biological phosphorus removal techniques highly valuable for agriculture (Nieminen et al., 2010). Phosphorus removal and recovery can be done through biological digestion process, chemical process, adsorption, dewatered liquor (Rashmi et al., 2020), sludge cake (Rashmi et al.,2021).

The primary advantages of EBPR are eradication of chemicals and also reduction in the sludge during the processes. Phosphate production in the sludge system increases under anaerobic circumstances as a result of a little release of the Poly-P held in the microorganisms during EBPR (Desmidt et al., 2015).

The phosphates typically stay in the metals by adhering to them following anaerobic treatment if the phosphorus concentration was eliminated chemically using aluminium salts or iron salts (Parsons et al., 2008).

The EBPR sludge contains nearly 5-7% of enriched phosphorus whereas the normal activated sludge contains only 1-2% of phosphorus content. After dewatering the rejection liquor or the phosphorus enriched sludge is used to recover the Phosphorus by various means like precipitation, crystallization ect., using various salts like calcium or magnesium and seed crystal to recover phosphorus as magnesium ammonium phosphate or calcium phosphate(Cornel et al., 2009). Phosphorus, which is a component of many macromolecules in the cell, is digested by a variety of microorganisms, including Pseudomonas, Moraxella, Mycobacterium, E. coli, Corynebacterium, Acinetobacter, and Aerobacter. Various organisms that are able to convert phosphorus into polyphosphates store it as a polyphosphate in volutingranules. Linear polymer of residues like Polyphosphate is linked by high-energy phosphoanhydride bonds and this may produce cellular dry weight upto 10 – 20% (Mc Grath et al., 2001). For the growth of micro-organism various cations are requires like magnesium, calcium iron and potassium which has to be above the limiting concentration in a culture media.

Therefore, this study is concentrated on providing a concise overview of the state-of-the-art in order to assess parameters that affect both the biological phosphorus removal and the stability and dependability of EBPR systems.

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2. Removal of phosphorous by EBPR

Enhanced reduction of biological phosphorous (EBPR) is the method where the phosphorous is eliminated through biological treatment that relies on the capacity PAOs to consume excessive phosphorus. This method decreases the expense of applying additional chemicals and therefore decreases the amount of sludge generated as opposite to chemical processes. Phoredox(A/O) is one such EBPR approach where the micro-organisms are exposed in the traditional stream to aerobic and anaerobic environments. The anaerobic and aerobic PAO metabolisms are schematically depicted in Figure2.1.

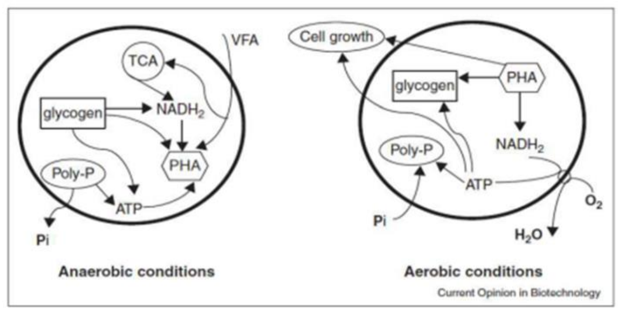

Figure 2.1 the anaerobic and aerobic PAO metabolism. (Yuan et al., 2012)

Hindrance of eutrophication can be effectively done by phosphorous removal in the wastewater using a closed water system. If the content of phosphorus is high, it leads to different water quality problems like recreation values will be low, the possibility of algal effects, loss in live-stock and treatment cost will be increased. Typically, chemical precipitation is used to remove phosphate from wastewater. Chemical precipitation is costly and also results in an increase in sludge production but the main advantage of this method is its relatively mere process. During this process the sludge increase was up to 30% of volume and also the sludge was contaminated with a high range of heavy metals. Hence it is necessary for an alternative of chemical precipitation for the removal of phosphorous.

When opposed to chemical phosphorus removal, one option that has noticeable advantages is biological phosphate removal. The sludge produced by biological phosphorus removal techniques has a high agricultural value since it is rich in phosphate availability and deficient in other undesirable compounds.

The primary advantages of EBPR are the eradication of chemicals and also a reduction in the sludge during the processes. The Poly-P held in the microbes is somewhat released under anaerobic circumstances following EBPR, which increases the phosphate synthesis in the sludge system. If the phosphorus content removed using chemical precipitation using aluminium salts or iron salts, the phosphates usually remain in the metals by binding to it after anaerobic treatment.

3. Factors Affecting Enhanced Biological Phosphorus Removal

3.1 pH

Selection of PAOs over GAOs can be done by increasing the pH, hence pH is important and highly influences the competition between PAO–GAO. The critical point of pH in anaerobic processes is that the GAOs take up VFA anaerobically higher than those PAOs at the pH below 7.25 whereas the PAOs take up acetate in a higher range only when pH is more than 7.25. The phosphorus removal efficiency is higher when the aerobic or/and anaerobic level of pH is raised from 7 to 8.5(Schuler et al., 2002) It is also assumed that the reason for the improvement in the performance is due to the change in the microbial competition from GAOs to PAOs. Zhang et al., (2005) observed, when there was a decrease in the pH from 7.0 to 6.5 a reduction of phosphate-removing organisms and variation in the microbial community was observed.

It has been noticed that at pH more than 8.0 there is a reduction in the phosphorus release, VFA uptake, and phosphorus uptake (Oehmenet al., 2005). EBPR process strongly depends on the pH of the liquor. With the increase in pH, the phosphorus release rate also increases. Bond et al., (1998) investigated that during anaerobic phosphorus release, it is not only built upon the pH of the mixed liquor but also on the intracellular pH.

3.2 Effect of pH on the Phosphorus/Acetate (P/Ac) ratio

At pH 5.0 to 6.5, the acetate absorption rate was stable while the phosphate release rate increased linearly; however, at pH 6.5 to 8.0, the acetate uptake rate decreased while the phosphate release rate increased. Therefore about 1.0 (pH 5.0-6.5) to 1.75 (pH 6.5-8.0) was the increase of P/Ac ratio (molar). Within the pH range 5.5-8.5 there was an increase in P/Ac ratio from 0.6 to 1.9 Smolders et al., (1994). The anaerobic phosphorus release decreases when the pH reaches 8.0 and more(Liu et al., 1996a).

Due to the chemical precipitation, there was a decrease of the P/Ac ratio at increased pH values (>7.5). The increase of the P/Ac ratio is described by the assumption that greater pH values give higher electrical potential difference beyond the membranes of the cell, i.e. to take up the negatively charged acetate ion more energy is needed for the cell. To adopt the same quantity of acetate at higher pH values than lower pH values there should be higher phosphate release by the bacteria. The total uptake of substrate during the anaerobic phase can rise, manifesting in a higher fraction of PAO in the process, to conceal the energy demand at low pH and the requirement for less phosphorus at lower pH. (Smolders et al., 1994).

3.3 Influence of intracellular pH

The intracellular pH of EBPR sludge was lifted in the existence of a weak base along with the substantial anaerobic phosphorus release, without any VFA uptake (Bond et al. (1998). The prohibition of anaerobic phosphate release was resulted still when VFA was present even though the acidification is caused by the acetic acid of the sludge.

These results may describe when, why supernatant pH is allowed to raise, the anaerobic phosphorus release increases even in sludges with phosphorus removing capabilities are extremely poor. Sludge characteristics are that almost no phosphorus transformation occurs even though at neutral pH values, acetate is taken up to a normal extent.

3.4 Temperature

In most biological reactions, the lower rate of biochemical transformations is due to the lower temperature in EBPR systems (Brdjanovic et al., 1998). Whereas in the lab-scale study, low temperatures are beneficial in improving EBPR performance (Panswad et al., 2003). The change in the process is due to the replacement of GAOs to PAOs by the microbial group. Whang and Park (2002) found at 20^{o}C SBR EBPR, performance was satisfactory whereas in another SBR with higher anaerobic acetate uptake at 30^{0}C there was a lower release and uptake level of phosphorus. Due to the increasing impact of GAOs high temperatures lead to a decrease in the performance of phosphorus removal. Compared to PAOs, GAOs can predominate at higher temperatures as GAOs increase the ability to uptake acetate at those temperatures. During summer months and warm climates, the competition between GAOs with PAOs in EBPR plants is highly complicated. $28\text{-}30^{0}$C is an optimum temperature for the better operation of the EBPR process. Christensson, (1997) stated that phosphorus removal is also achieved at 6^{0}C. Johansson (1994) observed that the temperature was raised from 10^{0}C to 20^{0}C and from 15^{0}C to 25^{0}C, respectively, two times of phosphate release was observed in the sludge. Studies also say that with the increase of temperature from 24^{0}C to 29^{0}C phosphorus release increases to 75% (Johansson, 1994).

3.5 Dissolved oxygen

The anaerobic zone's oxygen is used by heterotrophic aerobic organisms as an electron acceptor, and they compete with PAOs for VFAs, resulting in minimal VFA storage and, ultimately, less biological phosphorus elimination.

Excessive aeration has a detrimental impact on the biological phosphorus removal (BPR) process because it causes P-uptake to stop due to the reduction of poly-hydroxy-butyrate (PHB) in a high-aerated process (Brdjanovic et al., 1998).

It is also assumed that the competition between PAOs and GAO's is due to the concentration of DO, henceforth affecting the EBPR attainment. EBPR performance will be affected when the high concentration of 5mg/L DO is recirculating from aerobic to the anaerobic zone neglecting PAO and GAO completion.

Dissolved oxygen (DO), which facilitates the uptake of polyphosphates, is used up during the aerobic phase. At DO concentrations of 2 mg/L, a satisfactory phosphate uptake could take place when the sludge is aerated for a required amount of time (Christenssonet al., 1997). Tonkovic et al., (1998) stated that although a high DO level, aerobic respiration might be finite. This can occur if the amount and kind of carbon source added to sludge affects the performance of the microorganisms in an objectionable manner.

3.6 Carbon source

Carbon availability is one of the important factors, carbon in the mode of biodegradable COD/VFAs shows the advance of activated sludge plants for EBPR. The utilization source and price of carbon source are important hence the selection of carbon or substrate source is demanding (Puig et al., 2008).

Currently, there is an increased study on EBPR performance impact by propionate and various substrates. Studies explained that the downturn of phosphorus removal is due to the microbial competition between the GAOs with PAOs, whereas the use of carbon source as acetate in EBPR system is stated to be a stable phosphorus removal and yield robust performance (Oehmen et al., 2007). Investigations have proved that the use of propionate than acetate is much more advantageous for the successful performance of EBPR (Wang et al., 2010). PAOs and/or GAOs could take up VFAs other than propionate and acetate (Levantesi et al., 2002). It is been unclear that the above-mentioned substrate affects the PAO–GAO. The most broadly referred carbon substrate is glucose apart from VFAs (Jeon et al., 2000).

The carbon source such as acetate, ethanol, and others could produce the fastest growth of PAO (Johansson et al., 1994) The carbon source uptake has to be very quick from the microorganism as there is a limited time in the anaerobic phase (Christensson, 1997). To achieve high removal efficiency of nutrients in an SBR process along with carbohydrates such as glucose, acetate should be present in the media of nutrients.

To nourish the bacteria in the sludge there are various ways like external addition of industrial wastewater and external addition of acetic acid (Henze et al., 1996). Increased detention time due to internal addition VFA in the anaerobic tank by increased hydrolysis/fermentation. The type and quantity of carbon sources that the microorganism has access to play a key role in the EBPR process.

The acetic acid in the form of VFA is lesser in an amount in the sludge which is used by microorganisms hence, the amount has to be increased by fermentation or hydrolysis. For the induced high EBPR activity, ethanol is also a carbon source. In the anaerobic zone, a prolonged detention time is tedious when using ethanol as it is divided into VFA before the microorganism could take up.

3.7 Sulphate

Strongly alkaline circumstances also result in a decrease in free calcium and an increase in phosphate removal. A large quantity of sulphate in the solution might encourage the release of calcium from calcite, which will likely result in the formation of hydroxyapatite (Eardal et al., 2003).

3.8 Calcium

Calcium could be an important factor for the stabilisation but it is stated during a cycle the calcium concentration did not vary (Christensson et al., 1997). However, Miya et al., (1987) observed that when a large amount of carbon source is added, the calcium level drops during aeration, which raises pH. Phosphates are taken up and released more slowly as a result.m

3.9 Nitrate

Nitrate can act as an electron acceptor during the absence of oxygen. Hence it is significant that the water which enters into the anaerobic phase should not contain any nitrate. The condition leads to the same as aerobiosis, that is electron acceptor is served by nitrate and poly-hydroxybutyric acids(PHB) behalf of stored metabolism of intracellularly instead of a collection of new carbon source (Christensson et al., 1997).

3.10 Nitrate

The biological uptake of phosphorus is impacted by the presence of magnesium and potassium ions. Magnesium and potassium polyphosphates leak relatively quickly and lose stability in anaerobic environments. Phosphorus is released and taken up by counter ions magnesium and potassium in the EBPR sludge (Machnicka et al.,1999).

With the comparison of a variable in time rate of potassium and magnesium release, the release of phosphates is confirming that the possibility of simultaneous synthesis of intercellular and external polymers and also polyphosphates available in diverse forms. Change of rate of potassium and magnesium release in time has proved that there is a formation of different forms polyphosphates.

3.11 COD/P ratio

The ratio of influent COD or BOD to phosphorus is crucial for the effective operation and design of phosphorus removal systems. Each unit requires a stoichiometric amount of COD to remove phosphorus. The system that is constrained by COD (or BOD) or phosphorus determines how much excess phosphorus from the solution can be removed and how well PAOs can work. According to Oehmen et al(2007).'s research, PAOs tend to predominate at

COD:P ratios of 10–20 mg/mg-P while GAOs tend to predominate at COD:P ratios under 50 mg/mg-P. Hence, maintenance of good control over the operational condition and optimum COD:P ratio, the rivalry between PAOs and GAOs for substrates, which gives a positive outcome, needs to be used.

3.12 Cations

In maintaining the stability and binding of the mechanism of phosphorus in the EBPR process and activated sludge, composition as well as the concentration of cations in the influent plays a significant role. Phosphate molecules will not pass through the cell membrane by itself as it contains three negative charges, hence the phosphate molecules should bond with the positively charged ions like potassium and magnesium. As these two opposites charged molecules bonds each other, it develops into a neutral phase thereby phosphate molecules are easily passed through the cell membrane. It has also been observed that magnesium and potassium are not only required for neutralization but it is also one of the required cations in biological phosphorous removal.

The release of phosphate from PAO cells is a crucial step in the anaerobic stage of the biological phosphorous removal system. In the sewage treatment plants designed for EBPR process timely there will be a change in the influent short or long-term shortage of potassium whereas higher potassium content greatly influences the activated sludge properties and results in less efficient effluent quality and dewatering property (Schönborn et al., 2001).

3.13 Solid retention time (SRT)

SRT has been found as a variable that may impact the effectiveness of EBPR and rivalry between PAOs and GAOs. It has been shown in practise that good phosphorus removal may be accomplished with SRTs ranging from 3 to 68 days. Normally, the SRT has little effect on the EBPR process.

It has been demonstrated that increasing SRT decreases biomass output, which lowers the quantity of phosphorus eliminated through discharge of surplus sludge (Brdjanovic et al., 1998). According to (Barnard et al., 1993), SRT contributes less to phosphorus removal than one might anticipate given the context of EBPR.

The impact of the SRT in the EBPR system on PHA and glycogen polymerization reactions was explored while analysing the underlying biochemical techniques. GAOs and PAOs were able to successfully compete at a long SRT, which reduced the phosphorus removal efficiency in the EBPR system (Seviour et al., 2003). Shorter SRT is beneficial for PAO and suggests that GAO may tend to predominate at longer SRT, according to Rodrigo et al(1999) .'s observation that EBPR biomass activity reduced as the SRT was extended.

3.14 Dynamic stress state

Anaerobic stress imposition is a requirement and sufficient condition for the selection of POAs and other operational and/or environmental variables, as the organisms that accumulate poly-P may lack the energy to compete for the substrate in anaerobic environments (Gebremariam et al., (2011).

3.15 Feed composition

When glucose and acetate were combined in a reactor, a full anaerobic carbon absorption without any phosphorus release was observed, and the reactor sludge was found to be predominated by the G-bacteria group. Glucose improved the ability to inhibit EBPR and GAO growth.

In contrast, 50% of a mixture of glucose and acetate was shown to be more effective than acetate dosage in a sequencing batch reactor for removing phosphorus (SBR). There was a decline in phosphorus elimination at 75/25% glucose/acetate mixed diet (Gebremariam et al (2012). If the COD/P dose ratio was lower, the anaerobic-anoxic/nitrifying (A2N) process was unsteady.

4. Conclusion

Numerous aspects, including those affecting the processes, are taken into account when designing the enhanced biological phosphorus removal system. Most widely studied biological wastewater treatment processes is EBPR as it is efficient in removal of nutrients without using chemicals and also from the biological processes the end product would have manure value which is beneficial in the agricultural field. Large scale treatment plants show the excellent performance in the removal of phosphorus under demanding discharge limits on a consistent basis. But due to some trouble in the process, may lead to break down of the process and resulting in the violation of discharged limits. Moreover, still studies are going on to know some environmental and operating conditions. However, it is unclear how few operating and environmental factors affect the robustness and accuracy of EBPR systems.

A system's optimal pH level is acceptable for operation, sludge can be circulated between anaerobic and aerobic conditions, and the existence of potassium and magnesium ions causes the uptake of biological phosphorus in an EBPR system. As a result, it is extremely important to research, suggest, and control measures to benefit the increase of PAO and reduce the growth of GAO.

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