ISSN: 2395-7639

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

(A Monthly, Peer Reviewed Online Journal)

Visit: www.ijmrsetm.com

Volume 4, Issue 4, April 2017

Removal of Phosphates from Water Prevents Eutrophication

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ABSTRACT: Phosphorus removal from wastewater is essential to ensure the safety and health of the public and protect the environment. Elevated levels of phosphorus can be hazardous to local animal life. Removing phosphorus from water can prevent eutrophication, which causes algae blooms. While this may seem like a natural process, large-scale algae blooms will deplete the water of oxygen, causing dead zones and suffocating ecosystems. A disruption to the marine populations can have impacts to the food supply for larger land animals.Phosphorus also poses a risk to the safety of our drinking water. It is important to implement phosphorus removal systems to protect the well-being of ecosystems and drinking water.

KEYWORDS: phosphates, eutrophication, prevent, removal, algal blooms, dead zones, suffocating ecosystems

I.INTRODUCTION

While phosphorus is a necessary element, high levels of phosphorus can lead to multiple environmental complications in streams, lakes, rivers and coastal areas. A typical issue caused by elevated phosphorous in natural water sources is Eutrophication – a rampant stimulation of algae and other plants, leading to oxygen depletion in the water. These areas of oxygen depletion in water are known as dead zones.Dead zones will harm and kill various aquatic life forms, depleting both fauna and flora. “Fish Kills” are typically caused by these dead zones, when there is not enough oxygen in the water for the fish to survive. This can happen quickly. A healthy marine ecosystem may become a dead zone with hundreds to thousands of dead fish within a matter of days from the introduction to elevated phosphorous levels.When water is consumed, by both animals and humans, the algal toxins can be harmful. It is essential for phosphorous to be removed for drinking water. Furthermore, swimming the algal waters can cause skin irritations and illness.Wastewater contains highly elevated concentrations of phosphorous. Therefore, before discharging the water to local streams and rivers (where it may also flow to downstream drinking water plants), it is imperative that the phosphorous be reduced to safe levels. Fortunately, there are numerous treatment methods that can efficiently and effectively remove phosphorous.[1]

There are several forms of phosphorus removal, the most effect effective system will depend on the characteristics of the wastewater, the existing infrastructure at treatment facility, and the effluent phosphorous level required. Project budget, operator maintenance, and form of phosphorous should also be taken into consideration. Phosphorous removal systems can be broken down into 3 types – chemical, biological, and physical treatment systems.

Chemical Precipitation

Chemical precipitation, also known as a chemical phosphorus removal or primary phosphorus removal, can remove inorganic phosphates from water by adding a coagulant into the wastewater. During chemical precipitation, aluminum, calcium, or iron can be used as multivalent metal ions to form a phosphorous precipitate, which will then settle out of the wastewater.One common chemical additives is lime, Ca(OH)2, which contains calcium. Lime reacts with the wastewater’s natural alkalinity to create calcium carbonate and increase the water’s pH. Once the wastewater’s pH value has increased beyond 10, the calcium ions will react with the phosphate and precipitate as hydroxyapatite (a calcium phosphate).This reaction is between the lime and alkalinity of the wastewater, meaning the quantity needed will be independent of the amount of phosphate present in the water. Instead, it depends largely on the wastewater’s alkalinity and pH levels. The overall lime dose needed can be measured as 1.5 times the alkalinity as CaCO3. After this process, the wastewater may need to be neutralized to lower the pH levels before additional treatments or disposal.Aluminum or hydrated aluminum sulfate are also commonly used for precipitating phosphates.[2,3] The overall dosage rate is directly dependent on the level of phosphorus removal needed. The overall coagulation efficiency drops as the phosphorus concentration decreases.Necessary doses can be determined primarily using bench-scale tests and then verified during full-scale testing. Testing on actual wastewater samples (not imitation water created in the lab) is recommended due to chemical and polymer interactions with other constituents in the wastewater. Aluminum coagulants may negatively impact microbial levels in activated sludge, including rotifers and protozoa, when dosage rates exceed 150 mg/l.Ferric chloride or sulfate is also commonly used during ferric dosing for phosphorus removal. During phosphors removal, ferric ions can combine, creating ferric phosphate. Ferric ions react with the natural alkalinity, and a coagulant aid like lime can be added to raise the pH level to improve the coagulation process.[4,5]

Biological Removal

The biological phosphorus removal process, also known as secondary phosphorus removal, is an effective form of phosphorus removal filtration. Some of the main benefits of biological phosphorus removal from water include decreased sludge production and reduced chemical costs when compared to traditional chemical precipitation. Biological removal of phosphorus involves bacteria incorporating phosphorus into its cell biomass, helping to remove phosphorus in the process of sludge wasting.The reactor configuration provides the polyphosphate-accumulating organisms (PAO) with a unique benefit over other bacteria, encouraging PAO to grow and consume the phosphorus present. In biological removal implementations, there is an anaerobic tank before the aeration tank. Under these unique conditions, PAO is enriched within the bacterial community within activated sludge.In the following aerobic phase, bacteria can accumulate and process large amounts of polyphosphate in their cells, efficiently removing phosphorus. In general, all forms of bacteria contain a small amount of phosphorus within their biomass because of various cellular components, including deoxyribonucleic acid (DNA) and membrane phospholipids.[6,7]

As bacteria within wastewater consume and process these nutrients, they will continue to grow, incorporating phosphorus into their bacterial biomass. As PAOs develop, they also accumulate large quantities of polyphosphate within their cells.

Physical Removal

Physical phosphorus removal can be used independently or in combination with other types of phosphorus removal. The main types of physical removal, also of phosphorus from wastewater, also known as tertiary phosphorus removal, include membrane technologies and sand filtration. One example of physical removal of phosphorus includes retrofitting wastewater plants with a particulate phosphorus membrane technology.This particulate technology is ideal for long-term projects, which are most likely to benefit from this cost-effective solution over time. Membrane technologies tend to have a higher capital investment cost, meaning it may take many years to realize a return on investment. Because of this, chemical removal methods may be more initially cost-effective and easier to implement.[8,9]

Chemical Vs. Biological Phosphorus Removal

Chemical phosphorus removal uses precipitating phosphors with an aluminum salt or iron salt. Iron salt, including ferric chloride, can provide numerous benefits to reduce scum in secondary treatment processes and manage orders and sulfides in anaerobically digest sludge. Chemical phosphorus removal processes can also reduce struvite formation, which is often a compilation when a plant converts to a biological phosphorus removal system, reducing additional phosphorus in the digester.While chemical phosphorus removal systems are efficient and effective, it is important to note that they may increase sludge production rates and need additional storage requirements.Biological phosphorus removal may result in increased phosphorus levels accumulating in biological solids. The waste-activated sludge from the liquid stream removes these biosolids and phosphorus. To effectively implement biological phosphorus removal, an anaerobic-aerobic sequence is required to select for PAOs.Influent wastewater will go through the anaerobic zone. The PAOs can release phosphorus while collecting and storing carbohydrates with the absence of oxygen. After the anaerobic zone, the aerobic zone is where the PAOs can consume these carbohydrates while absorbing excess phosphorus. The anoxic zone is located between these two zones to remove nitrates from the return activated sludge.[10,11]

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II.DISCUSSION

Chemical Phosphorus Removal

Chemical phosphorus removal is a wastewater treatment process that uses iron, calcium or aluminum salts to remove phosphorus from the water. Phosphates create precipitates with metal ions and are removed with sludge in the separation unit. Chemical treatment for phosphorus is one of the most common methods to remove phosphorus and meet effluent concentrations below 1.0 mg/L.Chemical phosphorus removal is often less complicated than biological removal processes. The chemical treatment design consists of a mass balance between chemical addition and the concentration of phosphorus after the introduction of chemicals. Some of the pros and cons of chemical phosphorus removal include:

Pros

Chemical phosphorus removal is one of the most effective and commonly used phosphorus treatments, typically performed with iron and aluminum coagulants. Phosphorus removal is often required through special dedicated treatments, such as chemical treatments, to correct eutrophication problems. Some of the main benefits of chemical phosphorus removal include:

Effective: Chemical phosphorus removal is an effective phosphorus treatment to remove high phosphorus levels from water. Chemical treatments can create denser and easier to dewater sludge, which requires fewer polymers. Another benefit is fewer toxic and less corrosive chemicals, making for a cleaner and safer water plant.

Efficient: Chemical phosphorus removal treatments are also highly efficient and allow for phosphate removal across a wide range of pH values, especially when compared to traditional coagulants. Another benefit is enhanced settling and cleaner clarifiers.[12]

Cost-effective: Chemical treatments are also one of the most cost-effective phosphorus removal treatments, especially in the short term. While biological phosphorus removal is also cost-effective, this return on investment is not experienced for a few years and requires a long-term investment to be beneficial. Chemical phosphorus removal is most cost-effective in the short term and can minimize total expenses, helping realize a return on investment much sooner.

pH control: Finally, chemical phosphorus removal also enables a higher level of pH control, meaning there is little need to augment with caustic in an attempt to conserve alkalinity for nitrification or implement adjustments for final pH discharge limits.

Cons

While there are numerous benefits to chemical phosphorus removal systems, there are certain downsides to consider. Some of the most common cons associated with chemical phosphorus removal include:

Initial investment: With any phosphorus treatment, you will need to consider the total costs involved with these systems. You will want to consider the cost of the chemical feed system. In addition to this base structure, you also need to determine and assess the total costs of chemicals required for this system.[9,10]

Chemical sludge disposal: A chemical phosphorus removal system may cause chemical sludge reuse or disposal to be more difficult.

Phosphorus re-release: In some cases, digestion, specifically anaerobic digestion, may result in the re-release of phosphorus.

Chemical System Options

There are numerous chemical systems that can remove phosphorus from water, including chemical dosing to promote p-precipitation, absorptive media for p-removal and ion exchange technologies.

Chemical Dosing to Promote P-Precipitation

One of the most common chemical phosphorus removal options is chemical dosing to promote p-precipitation. Dosing with metal salts to pre-treated conventional activated sludge reactor or outlets from a secondary clarifier can effectively remove phosphorus from water.During chemical dosing, the addition of salt helps to precipitate phosphorus in water, and any resulting residuals or solids can be effectively removed by settling or a filtration system. The resulting precipitates are high in phosphorus, but the separation of chemically bonded phosphorus may be more difficult. This means efficient and effective phosphate recovery is unlikely for further use. Because of this, there is a potential disadvantage over other biological phosphorus removal systems because it may reduce the overall economic benefits of downstream uses for phosphorus-rich sludge.Phosphorus removal rates are often proportional to the amount of chemicals added, influencing the total number of solids produced. Because of this, there are cost benefits to the amount of salt used and the method employed for solid separation.In some cases, additional techniques, such as tertiary-ballasted flocculation and filtration, may also be used in addition to salt dosing to achieve lower phosphorus effluent levels with less addition of salt. In most cases, chemical dosing is reliable, effective and widely used, making it one of the most commonly used techniques. Although chemical dosing is effective, it may not be ideal for smaller plants or projects.

Absorptive Media for P-Removal

Phosphorus removal can also be achieved using active media. Reactive media filters rely on phosphorus sorption processes of material to reduce phosphorus levels in a more targeted and refined manner instead of using a filter media. Absorptive media are created from industrial waste products, artificial products or natural products. A commercially available product for this process is Polonite, which has been shown to achieve high rates of phosphate removal.Phosphorus is removed with a filter media during the process of direct precipitation or sorption, involving the movement of inorganic phosphorus from wastewater to the surface of reactive components within the media. Therefore, the phosphorus removal capacity is dependent on the media's mineral content. While early applications of p-removal revolved around sorptive media using locally sourced gravel and sands. Recent innovations have developed many artificial and natural materials for the application of this procedure at a smaller scale.[7,8]

Ion Exchange Technologies

Ion exchange technologies are a well-established and reliable process used in the deionization or desalination of water. Additionally, ion exchange is also useful to remove phosphorus from wastewater. While ion exchange technologies may not be as common as other chemical phosphorus removal techniques, this technology is still highly effective and efficient in certain situations.The most common form of phosphorus in wastewater is anionic. Phosphate ions are interchanged reversibly between the solid ion exchange and liquid wastewater, which aids in removal and recovery. Immobilized particulars of the metal cation form the polymer exchange base where p-selective nanoparticles are placed. This approach helps the selection of p anions in water over other ions, including chlorides or sulfates.

III.RESULTS

Biological Phosphorus Removal

Biological phosphorus removal is a wastewater treatment process used to remove phosphorus from water. Biological phosphorus removal implementations use a group of heterotrophic bacteria to process excess phosphorus levels from water. Some of the main pros and cons of biological phosphorus removal include:

Pros

Biological phosphorus removal uses bacteria and alternating anaerobic and aerobic conditions to promote phosphorus uptake. Some of the main benefits of biological phosphorus removal include:

Operating costs: One benefit of biological phosphorus removal is lower total operating costs. Because biological phosphorus removal does not require the use of chemicals, you can also realize savings on these chemical additions.[6,7]

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Sludge volume: Chemical phosphorus treatments also help create lower sludge volumes, minimizing total sludge disposal costs. Compared to chemical removal, biological removal can reduce the total amount of sludge production.

Safe: Biological phosphorus removal also has many aspects, making it a safe option for humans and the environment. For example, there are less chemical handling and lower greenhouse gas emissions from chemical production and shipping. Also, biological phosphorus removal helps to incorporate phosphorus into sludge for easier management and removal.

Cons

Despite biological phosphorus removal being an effective phosphorus removal technique, there are certain aspects of these processes you should consider. Some of the main cons of biological phosphorus removal include:

Complex: Biological phosphorus removal is considered a rather complex process, which may not make it ideal for smaller applications. Despite it being a complex process, biological phosphorus removal is an effective method for nutrient removal.

Economic benefits: In some instances of biological phosphorus removal, the separation of chemically bonded phosphorus may be difficult, causing efficient phosphorus recovery to be unlikely for further use. This may present an overall disadvantage in some cases because it limits the overall economic benefits of using phosphorus-rich sludge.[4,5]

Biological System Options

Some of the most common biological system options include identification of PAO, metabolism of PAO, traditional enhanced biological phosphorus removal (EBPR), novel EBPR systems and potential EBPR systems.

Identification of PAO

Biological phosphorus removal typically occurs with the accumulation of phosphorus by microorganisms that go beyond typical requirements for metabolic processes. Phosphorus occurs as polyphosphate and is retained as a reserve of energy to provide a competitive advantage over heterotrophs or maintenance.

Because of this, PAOs often outcompete other organisms. One exception is the presence of glycogen accumulating organisms (GAO). One of the most widely studied and used PAOs includes the candidates accumulibacter phosphates and is used as the basis for most metabolic models. Accumulibacter is considered the predominant PAO in efficient EPBR systems.

Metabolism of PAO

The development of PAO can be promoted by optimizing various operating conditions, including aerobic or anoxic and cycling phases. Within anaerobic conditions, PAO uptake of volatile fatty acids using secondary transport and storing them as polyhydroxyalkanoates (PHA). The energy required for this process is procured from adenosine triphosphate (ATP), which is created by the degradation of glycogen and internally stored polyphosphate.[3,4]

When polyphosphate breaks down, it releases orthophosphate into the bulk liquid. When PHA is created under anaerobic conditions, it requires the reduction equivalent of nicotinamide adenine dinucleotide (NADH), which is provided via glycolysis or the tricarboxylic acid (TCA) cycle. Using glycolysis has been shown to provide efficient and effective phosphorus removal rates.

Traditional EBPR Systems

Traditionally, biological phosphorus removal systems have been used in conventional activated sludge systems. As technology advances, research has focused on the effect of implementing biofilm carriers on overall system performance and the effects of environmental and operational parameters regarding metabolic behavior and microbial diversity.

The overall amount of biological phosphorus removal is directly related to the total number of PAO present within the system. EBPR has been used in membrane bioreactors (MBR), sequencing batch biofilm reactors and granular sludge reactors. Implementing EBPR in these systems has shown to achieve high phosphorus removal rates from municipal wastewater.[2,3]

Novel and Potential EBPR Systems

Phosphorus removal and EBPR systems continue to advance and become more effective and efficient. New and efficient MBR system configurations have been developed with the goal of enhancing nutrient removal. One example of this is sequencing batch moving MBR, which achieved impressive phosphorus removal rates.While new and potential EBPR systems are quite promising, continuing research into the consistency and reliability of these technologies is needed. Additionally, the operational, capital and environmental costs of these newer applications will also need to be evaluated.A novel system for granular sludge in single systems used under anaerobic-anoxic conditions for phosphorus removal. This technology is known as AnoxAn and is designed to achieve multi-nutrient removal. The up-flow design of this system provides cost and space savings in regards to energy and mixing requirements, making it potentially ideal for biological phosphorus removal.[1]

IV.CONCLUSIONS

Choosing a Phosphorus Removal System

While phosphorus is an essential nutrient in small amounts, large concentrations in wastewater can lead to a toxic and dangerous situation. Choosing a phosphorus removal system for your needs can help maintain safe phosphorus levels in wastewater and reduce the risk to plant, aquatic and wildlife, and human health.When choosing a phosphorus removal system, it is important to use a system that meets the scale and scope of your project. In most cases, it is recommended to choose a phosphorus removal system with extensive research for efficiency, safety effectiveness.[12]

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ISSN: 2395-7639

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Visit: www.ijmrsetm.com

Volume 4, Issue 4, April 2017

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