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REFINEMENT OF AN ESTABLISHED WASTEWATER PROCESS TO ACCOMPLISH BIOLOGICAL NITROGEN REMOVAL: A REVIEW

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Refinement of an Established Wastewater Process to Accomplish Biological Nitrogen Removal: A Review

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Abstract – Water shortage is becoming an increasing dominant problem in many coastal areas in both low and high income countries. Due to rapid urbanization and climate change, traditional measures (like water saving, fresh water transport from far away or rainwater harvesting) and advanced solutions (sea water desalination by reverse osmosis) become insufficient, less cost effective and/or environmentally unsustainable in matching the ever growing water demand. Advanced water treatment is being required to meet water quality objectives in that water in which the growth of aquatic plant, algae is excessive and causing biological impact the growth of these photosynthetic organism is being stimulated by available nutrients (phosphorus and nitrogen) that are normally limiting in natural waters. As effluent discharge permit limits become more stringent, utilities are constantly searching for efficient and cost effective methods to meet these tighter restrictions. Many different technological strategies have been developed that attempt to address this growing concern. This paper illustrates and describs the design, which utilizes an innovative process to maintain an optimum biomass concentration within the media.

Keywords: Biological Nutrient Removal, Nitrogen Nutrient Removal, Nitrogen Removal, Phosphorus Removal.

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1. INTRODUCTION

Biological nutrient removal (BNR) is commonly the most economical means of removing nitrogen and phosphorus from wastewaters without the use of chemicals to control eutrophication in lakes and estuaries, and to prevent the gradual deterioration of water quality. Loss of recreational and economical value of a water body is unavoidable if controlled discharge of wastewater streams is not practiced. However, there are current gaps in the knowledge of enhanced biological phosphorus removal (EBPR) that have restricted its widespread adoption compared to nitrogen removal. These gaps need to be filled before it will receive the widespread implementation it deserves. Removal of nitrogen is successfully and widely practiced because the biological and biochemical mechanisms behind the processes are well-known, and they are not as complicated as those of EBPR. For these reasons, EBPR has been left on the back burner although it has significant economic advantages and its implementation would make nitrogen removal more efficient while also reducing some of the stress on nitrogen removal. Currently nitrogen removal goals that need to be attained are getting much stricter and it is becoming more imperative that phosphorus removal be accomplished, because phosphorus is nearly always the limiting nutrient for freshwater bodies, and is seasonally or regionally limiting for estuarine bodies of water. There is a need to increase the number of wastewater treatment plants that practice EBPR in addition to nitrogen removal, but a better understanding of its economic and process optimization advantages is needed by the wastewater treatment profession. One way to accomplish this would be through a better understanding of the biochemical mechanisms and microbial population dynamics that determine the reliability and efficiency of EBPR, and through the utilization of this information to improve the design and operation of BNR plants. Such knowledge will also contribute to better structure of modeling tools that are used for design and educational purposes.

One such model is the Activated Sludge Model and it lacks the necessary information to accurately describe and predict the phosphorus removal capacity of a BNR plant design since it is not based on a complete biochemical model for EBPR Biological nitrogen removal in wastewater treatment occurs by two primary mechanisms: 1) biomass synthesis (nitrogen assimilation) and sludge wasting, and 2) biological nitrification and denitrification, with only the latter able to achieve high levels of nitrogen removal and low effluent concentrations of inorganic nitrogen in biological nutrient removal processes treating domestic wastewaters. Nitrification is a two-step process in which one genus of aerobic bacteria oxidize ammonia -nitrogen (NH_3-N) to nitrite-nitrogen (NO_2-N) followed by another genus which oxidizes nitrite nitrogen to nitrate-nitrogen (NO_3-N). Under certain conditions, e.g. inadequate dissolved oxygen, the process can be stopped at NO_2-N formation. In biological denitrification, a carbon source is oxidized using nitrate and/or nitrite as electron acceptors in biological oxidation-reduction reactions to reduce the oxidized nitrogen (NO_3-N or NO_2-N) to inert nitrogen gas (N_2).Various programs exist throughout the world to control the effluent from wastewater treatment plants (WWTPs) and address the adverse effects of nutrients on water quality, both domestic and industrial. These WWTPs are called point sources as they release nutrients to the environment from a defined source such as a pipe, outfall, ditch, or similar conveyance.

Typically during wastewater treatment, organic nitrogen and ammonia nitrogen are either converted to nitrates or removed as nitrogen gas to the atmosphere. Phosphorous is typically removed with the sludge following conversion to a chemical precipitate or incorporation into the biological cell mass. Nonpoint sources also contribute significant quantities of nitrogen and phosphorous. Nonpoint sources for nutrients can be, for example, storm water runoff, snowmelt, and atmospheric deposition. For water quality programs to be successful, it is often necessary to control these nonpoint sources as well. All sources of water entering lakes and reservoirs (i.e., rivers, creeks, groundwater, atmosphere, and rainfall and wastewater effluent) can contribute nutrients. In some instances, contributions from nonpoint sources may be so great that benefits from removal of nitrogen or phosphorous from point sources become insignificant. The various options available for removing or converting nitrogen from one species to another. As the figure 1 shows how nitrification and denitrification occurs.

To completely remove nitrogen from the system, five processes are available:

1. Conversion of nitrogen to nitrogen gas (N_2), which escapes into the atmosphere. This process is achieved in biological treatment systems through nitrification, followed by denitrification (breakpoint chlorination).

2. Biological uptake of nitrogen for growth of biomass.

3. Stripping of ammonia from the water because NH_3 (g) can be achieved at high pH.

4. Ion exchange to chemically exchange nitrogen ions as NH_4^+ or as $N0_3^-$ using a cation or anion exchange resin, respectively.

5. Processes that will remove essentially all pollutants from water, such as reverse osmosis membranes, can be used to remove nitrogen. Efficiency varies with the type of membrane and nitrogen species.

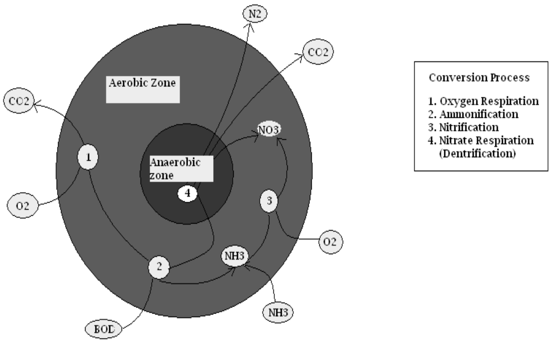


Fig. 1: Conversion Process

2. OVERVIEW OF NITROGEN AND PHOSPHORUS REMOVAL TECHNOLOGIES

It presents findings from an extensive review of nutrient removal technologies and techniques currently applied and emerging at wastewater treatment plants. It is important to recognize that the industry is always changing and that new technologies not identified in this paper may emerge in the future. New technologies may be innovative adaptations of existing technologies or technologies borrowed from another industry, and some could lead to considerable performance improvements and cost savings. When evaluating new technologies, designers and plant owners should work closely with their state regulatory agency and use the basic treatment principles. The technologies that are available today (in use and emerging) that can achieve biological nitrogen, phosphorus and nitrogen/phosphorus combined removal. Discussion of each technology follows the Table 1, 2, and 3 respectively.

Table 1 Phosphorus Removal Processes

Configuration	Type	Technology
Chemical Precipitation	Pre, Co, Post-Precipitation	Lime addition
		Metal salt
Biological	Suspended Growth	Anaerobic/Oxic(A/O),i.e. Phoredox
	Hybrid	Phostrip

Table 2 Nitrogen Removal Processes

Configuration	Type		Technology	
Single Process Unit For Nitrification & Denitrification	Biological	Suspended Growth	Wuhrman	
			Ludzack-Ettinger	
			Modified Ludzack-Ettinger (MLE)	
			4-Stage Bardenpho	
			4-Stage Bioreactor Bardenpho With	
			Sequencing Batch Reactor (SBR)	
			Oxidation Ditch With Anoxic Zone	
			Step Feed Biological Nitrogen Removal	
			Simultaneous Nitrification Denitrification	
		Attached Growth	Integrated Fixed Film Activated Sludge (IFAS)	
			Moving Bed Biofilm Reactor (MBBR)	
			Rotating Biological Contactors (RBC)	
			Suspended Biological Contactors (SBC)	
			Ringlace	
			Wave Oxidation System	
			Counter Current Aeration	
			Intermittent Cycle	
	Physical/ Chemical		Breakpoint Chlorination	
			Ammonia Stripping	
			Ion Exchange	
			Membrane Processes	Reverse Osmosis
				Nano-filtration
Separate Stage- Nitrification	Biological	Suspended Growth	Nitrification Only	
		Attached Growth	Biological Aerated Filters (BAF)	
		Fixed Film	Trickling Filter	
			Aerobic Filter	
Separate Stage- Denitrification	Biological	Attached Growth	Denitrification Filters Down flow & Up flow Continuous Backwash	
		Fixed Film	Trickling Filter	
			Filter	
			Activated Sludge Fluidized Bed	

Table 3 Nitrogen & Phosphorus Removal Processes

Configuration	Type	Technology
Biological	Suspended Growth	3 Stage Phoredox (A2/O)
		5-Stage Bardenpho
		Modified University of Capetown
		Westbank Configuration
		Oxidation Ditch with Anoxic and Anaerobic Zone
		Sequencing Batch Reactor (SBR)

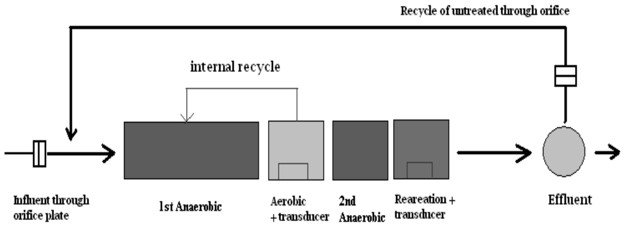
3. METHODOLOGY SUGGESTED BNR SCHEMES

Selection of treatment processes for plant upgrades is based on many factors including target effluent limits, existing treatment, space available, and operator preference. Selection is more of an art than a science and is influenced by the experiences and preferences. But complete nitrification can be achieved in warmer months using relatively short solids residence times (SRTs), the volumes of biological reactors and secondary clarifiers can be significantly reduced if the plant has a seasonal. The space available at the plant for upgrades can be the driving factor for selecting amongst various types of nutrient removal technologies. Technologies requiring large footprints may not be feasible in an urban area with limited space available for expansion. If space is limited, there are many alternatives for reducing basin requirements for nitrification and denitrification. Now the addition of any commercial chemical requires delivery, storage, and safety procedures in addition to mixing and dosing equipment. It also should carefully consider the impacts of sludge processing on nutrient release into recycle streams.

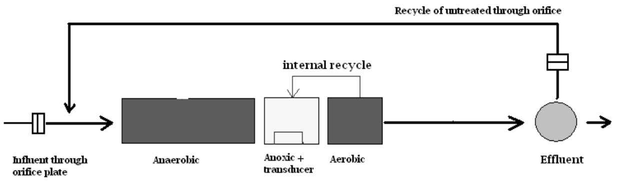
Treatment plant upgrades for nutrient removal often require additional energy to operate. Nutrient removal may be required for very small or decentralized wastewater treatment applications. Unique features of these treatment applications with regard to wastewater characteristics, operations and maintenance capabilities, and water reuse potential affect the process selection and design approaches. Any liquid can be prepared in a metastable state with respect to its vapor in two ways: either by superheating above its boiling temperature T_b, or by stretching below its saturated vapor pressure *P*sat. It will eventually return to equilibrium by nucleation of vapor bubbles (cavitation). This phenomenon is of fundamental interest known as cavitation. A novel method of treating influent has been studied by hydrodynamic cavitation Hydrodynamic cavitation occurs when a liquid undergoes a dynamic pressure reduction due to constriction devices like venturi, orifice plates, etc., while operating under constant temperature. Phenomenon of the hydrodynamic cavitation results in the formation of cavities filled with a vapor gas mixture inside the liquid flow or at the boundary of the constriction devices due to a local pressure drop caused by the movement of the liquid. Mixing, emulsification, homogenization and dispersion are some of the commonly studied areas using this cavitation as well as acoustic cavitation. These effects are due to a substantial plurality of force effects acting on the treated mixture of components due to the collapse of the cavitation bubbles. It has been recognized for many years that power ultrasound has great potential for use in a wide variety of processes in the chemical and allied industries. Reported applications include cleaning, sterilization, flotation, drying, degassing, defoaming, filtration, homogenization, emulsification, dissolution, deaggregation of powder, biological cell disruption, extraction, crystallization and as a stimulus for chemical reactions.

Considerations with the effect of cavitation, sonochemistry, ultraviolet ray effect these are some suggest schemes can be used in removal of phosphorus and nitrogen combined. It includes possibility of use of some schemes which only gives upgradation not include any modeling, design, simulation the actual work can be done by using this concept is conceptually possible. There are several of the BNR schemes used to take advantage of the biological nitrogen transformations. This list is by no means complete, but it demonstrates the variety of possible ways to achieve nitrogen removal. These processes are not explained in depth.

Basis of these schemes (1, 2, 3, and 4) as shown below; is the 5-stage Bardenpho process & Modified Ludzack-Ettinger consists of the 4-stage process with an anaerobic zone added to the front of the system. Nitrate rich liquor is recycled from the first aerobic stage to the first anoxic zone. The untreated effluent is recycled from the clarifier to the beginning of the anaerobic zone. They do not have the potential to significantly interfere with the phosphorus removal process as with the Phoredox configuration. Methanol, ferric chloride might need to be added to the second anoxic zone for complete denitrification or to minimize the volume of the second anoxic zone. So that to operate the system to achieve simultaneous nitrification and denitrification at different locations within the same scheme by controlling environmental (such as dissolved oxygen) and hydrodynamic (mixing) conditions. Also the system can modify as replacing orifice by venturi, jet, nozzle, swirling jet, etc.



BNR SCHEME NO. 1



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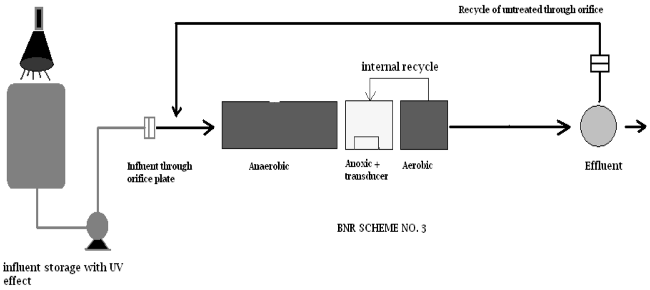
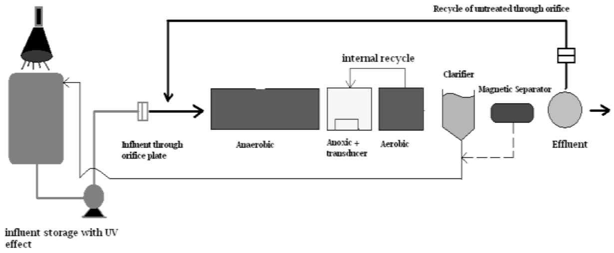


BNR SCHEME NO. 3



BNR SCHEME NO. 4

4. DISCUSSION

Benefits

- Reasons for using BNR processes for the treatment of wastewaters may be classified as environmental benefits, economic benefits, and operational benefits. The most important of these is the control of eutrophication in the effluent receiving water as an environmental benefit. Historically, treatment requirements were determined by the need to protect the oxygen resources of the receiving water, and this was accomplished primarily through the removal of putrescible solids and dissolved organics from the wastewater before discharge. More recently, considerable emphasis has been placed on also reducing the quantities of nutrients discharged (nitrogen and phosphorous) because they stimulate growth of algae and other photosynthetic aquatic life, which leads to accelerated eutrophication, excessive loss of oxygen resources, and undesirable changes in aquatic populations. The potential impact of discharged nutrients on the oxygen resources of receiving waters can be best illustrated by looking at the amounts of organic matter that can be generated by these nutrients compared to the amount of organic matter in untreated sewage. Much of the biomass will slowly biodegrade, but the organics will build up in the bottom sediments where long term biodegradation occurs, and it is likely that a high percentage of sediment oxygen demand (SOD) will eventually be exerted. The rate of SOD will also accelerate as the biomass accumulates. Considering that phosphorous is a conservative substance that will accumulate within the system, it is clear that all comprehensive eutrophication control efforts should include phosphorous removal from discharged wastewaters. Either nitrogen or phosphorous can be the nutrient that determines the limit biomass growth. Either nitrogen or phosphorous will probably be the limiting nutrient that controls eutrophication because of the relatively large quantities required for biomass growth compared to other nutrients such as sulfur, potassium, calcium, and magnesium.

- Conventional wisdom in recent years has been that phosphorous is typically the limiting nutrient in freshwater environments, whereas nitrogen is typically limiting in estuarine and marine waters. The relationships are actually considerably more complex than this generalization states because conditions in most lakes, reservoirs, and estuaries are dominated by bottom sediment conditions and seasonal changes. Because the limiting nutrient dynamics are generally poorly understood for most bodies of water, the best eutrophication control policy is simultaneous reduction of both nitrogen and phosphorous inputs. Also, because of seasonal changes, it is typically necessary to control both point and nonpoint sources in a complex watershed to attain the desired water quality. BNR processes provide a capability for the removal of nitrogen and phosphorous that is both environmentally and economically superior to other options.

- Additional environmental benefits of BNR compared to phosphorous precipitation and methanol nitrogen removal are reduced chemical consumption, reduced waste sludge production, and reduced energy consumption by the treatment system. Such reductions lessen overall operational and disposal requirements and provide the primary economic benefits of BNR. Converting activated sludge systems to provide biological phosphorous removal (BPR) by incorporating an anaerobic zone ahead of the aerobic zone will result in substantial aeration energy cost reductions of possibly 10 percent. A biological nitrogen removal process is always more economical to operate than a fully aerobic one accomplishing complete nitrification. Typically, nitrification will increase energy costs by 50 percent for the treatment of domestic wastewaters, compared to requirements for COD removal only. Incorporation of an anoxic zone ahead of the aerobic zone in such a system will always result in a reduction of the total aeration energy costs. Anaerobic and/or anoxic zones placed ahead of aerobic zones help discourage the growth of filamentous microorganisms in activated sludge and generally improve the sludge settling properties.

- The performance of a BNR system is strongly affected by the characteristics of the wastewater influent to each zone of the process. Neither biological nitrogen removal nor biological phosphorous removal can be accomplished without sufficient biodegradable organic substrate (i.e., as measured by COD or BOD). Efficiency of BPR varies with the specific organic compound available in the anaerobic zone. The efficiency of both nitrogen removal and phosphorous removal can be reduced by conditions that result in the metabolism of usable substrate by other biochemical pathways. Primary settling will substantially reduce the ratio of organic matter to phosphorous in the wastewater, and reduce the amount of phosphorous and nitrogen that can be removed by the treatment plant. Recycle streams from sludge processing will have the same effect.

LIMITATIONS

- There has been considerable confusion concerning the lower limits of phosphorous and nitrogen concentrations possible with BNR processes.

- Effluent nutrient standards for wastewater treatment plants should be set only after full consideration of the seasonal nature of nonpoint nutrients, the magnitude of atmospheric inputs, and the economics of different levels of wastewater treatment.

CONCLUSION

- A variety of nutrient removal processes exist: chemical, physical, and biological. This paper focused on the most cost-effective process, biological. Within the biological processes, a variety of treatment options exist for both nitrogen and phosphorous.

- The enhanced biological phosphorus removal phenomenon could be manipulated to provide controlled and predictable removal efficiency.

- A key element of these processes was the ability to separate out the biological nitrogen and phosphorus removal mechanisms to minimize the amount of nitrate entering the anaerobic zone, which has a detrimental effect on biological phosphorus removal.

- The selection of the main BNR process configuration is dependent upon effluent quality limitations, historical influent average and peak month characteristics, and the expected minimum and maximum monthly mixed liquor temperature.

- The objective this paper to develop a framework for insuring that water quality and quantity needs of the region could be safeguarded for the foreseeable future

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