An Analysis of U.S. Wastewater Treatment Strategies and Technologies for Nitrogen Removal

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In 1969, Ohio's Cuyahoga River had been so completely toxified by industrial pollution that the river caught on fire. This event became the symbol for out-of-control pollution needed to fuel public outcry for protection of the waters they so heavily relied upon. In 1972, the Clean Water Act (CWA) was passed to not only control pollution in water systems but to put forth a policy that required clean-up and maintenance of the system. Funding was provided to construct wastewater treatment facilities and regulations were implemented to determine the requirements for water quality standards.[1]

In the United States, there are over 16,000 municipal wastewater treatment facilities. These facilities account for approximately 75% of the nation's wastewater demands. The remaining 25% use septic or other onsite systems.[2] The CWA requires that all municipal wastewater facilities provide, at minimum, some form of "secondary treatment" for all wastewater affluent. This means that all facilities must provide some degree of biological treatment to remove organic matter. The U.S. Environmental Protection Agency (EPA) is responsible for determining effluent nutrient limitations discharged into water systems. These limitations, however, may not fully account for the dramatic changes that have occurred in the use of nitrogen due to human enterprise. Only approximately 30% of US WWTPs have systems that provide cleaner water through greater levels of treatment. This issue is even more impacted due to aging infrastructure and decreases in funding for upgraded systems.

Today, there are many common sources of nitrogen entering environments that are not part of the natural nitrogen cycle of our planet. Fertilizers, food preservation, septic systems, pharmaceutical manufacturing, coolant, stainless steel production, and others are adding increased nitrogen levels to the environment. These human impacts have devastating effects on aquatic systems such as oxygen dead zones, fish kills, and harmful algae blooms (HAB).[3] Nitrogen supports the growth of algae and

[1] (How a Burning River Helped Create the Clean Water Act, 2015)
[2] (National Service Center for Environmental Publications (NSCEP) - Primer for Municipal Wastewater Treatment Systems, 2004)
[3] (Biological Nutrient Removal , 2021)

aquatic plants which provide food and habitat for fish, shellfish, and other smaller organisms that live in the water, but the increase in nitrogen in areas like estuaries can cause algae to grow faster than the system can handle, causing eutrophication. These blooms can reduce or eliminate oxygen in the water, lead to toxins that effect fish and other wildlife, and can have severe effects on human health and commerce.[4]

Current Wastewater treatment strategies

All municipal WWTPs in the U.S. require a minimum of a primary and secondary stage treatment process. The primary stage is designed to remove large debris. This is typically done with screens that catch material as the wastewater enters the facility. Screens can vary from course to fine, using parallel steel or iron bars, with openings of about a half an inch.[5] Other screens may be much smaller and made from a mesh. The second part of the primary treatment stage is sedimentation. Settling tanks are used to allow larger material to settle to the bottom. This process can be assisted by using coagulants or further filtration. Once settling is maximized, material on the bottom is removed and the water is passed on to the secondary treatment stage.

Secondary treatment for wastewater is a biological process. The primary techniques are activated sludge and trickle filtering. Activated sludge relies on the development of a mixed culture of micro-organisms to metabolize pollutants in wastewater.[6] There are several components that are needed for activated sludge. 1. Micro-organisms – microbes and bacteria that are used to remove pollutants. 2. Food – organic matter or any carbon source. 3. Oxygen control – oxygen is needed for nitrification, and anoxia is needed for denitrification. 4. Mixing – this is needed to maintain a consistent environment

[4] (James N. Galloway, 2013)
[5] (National Service Center for Environmental Publications (NSCEP) - Primer for Municipal Wastewater Treatment Systems, 2004)
[6] (National Service Center for Environmental Publications (NSCEP), 2004)

suspended in the tank. 5. Solids management – to determine removal or reuse of the sludge and control micro-organism numbers.[7] These processes require constant monitoring and testing to ensure that contaminants are removed completely, and nutrient levels are within the established permit limits.

A trickling filter is another type of secondary treatment that uses a bed of rocks or interlocking corrugated plastic as a filter system. Bacteria grow on the surface of the rocks and as the water runs through, the bacteria remove organic matter from the water. The cleaner water runs out of the bottom of the filter tank and is generally moved to another settling tank and then chemically treated.[8]

Once secondary treatment is completed, water is transferred to a final stage for sterilization. There are several options for this process including chlorine and ultraviolet light treatment.

New Technology

Anammox – Anaerobic Ammonium Oxidation

Discovered in the early nineties, Anammox bacteria can transform ammonium and nitrogen dioxide directly into nitrogen gas and water in a single process. There are several advantages to this system. 1. The addition of oxygen can be greatly reduced, 2. Anammox bacteria do not require organic carbon input, 3. CO_2 emissions are reduced, and 4. Sludge production is decreased. This can lead to substantial cost savings for WWTPs over a long period of time.

There are several Anammox treatment processes. The first is called Two Reactor Nitritation-Anammox Process. Here, ammonium is first partially oxidized to nitrite. Then, the nitrite is reduced to elemental nitrogen using the remaining ammonium in the Anammox reactor. This process is often referred to as

[7] (National Service Center for Environmental Publications (NSCEP) - Primer for Municipal Wastewater Treatment Systems, 2004)
[8] (National Service Center for Environmental Publications (NSCEP) - Primer for Municipal Wastewater Treatment Systems, 2004)

System for High Ammonia Removal Over Nitrite (SHARON). Currently, this system is only being utilized with ammonium rich effluents.

The second is called One Reactor Nitritation – Anammox Process. This process, called Completely Autotrophic Nitrogen Removal Over Nitrite (CANON) uses ammonium oxidizing bacteria and Anammox bacteria at the same time in a two-step reaction under limited oxygen.

The third option is called One Reactor Denitrification – Anammox Process. Known as Denitrifying Ammonium Oxidation (DEAMOX), it combines the denitrification and Anammox processes. This technology is new, and research on its capabilities is ongoing. The primary use for this system is for the treatment of wastewater with high nitrogen and organic carbon levels. This would be a very effective process for landfill leaching and digested animal waste.[9]

Overall, the use of Anammox bacteria coupled with other technologies looks to be an effective process for dealing with increased needs for nutrient removal in wastewater. Though there are many pros to this system from both a cost saving perspective as well as an environmental view, there are some cons. Anammox is a very new and complicated technology. Initial implementation will be slow and expensive and require a highly trained staff and constant sampling.[10] However, once operational, the Anammox systems show strong promise for long term cost savings and water quality improvement. Completed in 2002 in Rotterdam, Netherlands, the first full-scale Anammox treatment facility was put into operation. With a small footprint, the new facility was built just below the main treatment facility and is used for removal of ammonium from the plant's digestive reject water. The system has demonstrated drastic decreases in ammonium and nitrogen and a substantial cost benefit through reduced use of methanol.

SPD – Solid Phase Denitrification

[9] (ShadiRahimia, 2020)
[10] (Mohd Najibul Hasan, 2021)

SPD, which uses solid substances involving natural plant-like materials and synthetic biodegradable polymers, serves as a carbon source for the denitrification process.[11] This process has shown to be effective in the removal of nitrogen from drinking water, groundwater, and aquaculture systems. The use of SPD in wastewater as a tertiary treatment, or as an addition to current secondary biological treatment could be effective at further nitrogen removal.

Conclusion

The process of biological nutrient removal (BNR) from wastewater is an ongoing challenge. Conventional systems designed to meet secondary treatment effluent standards are not able to remove total nitrogen (TN) to a level needed to protect receiving waters from rising nutrient inputs. Today's WWTP systems are being challenged with finding new innovative approaches to dealing with the increased nutrient loads from wastewater. With aging infrastructure and high costs associated with newer technologies, WWTPs are struggling to keep up with the demand. As impacts on water bodies continue to rise, there is a need for collective infrastructure support to help mitigate the effects of eutrophication, toxic algae, dead zones, wildlife impacts and human health due to excessive nutrient loads. There will also need to be a concerted effort to drive infrastructure advancements through continued pressure on water quality standards. When Ohio's Cuyahoga River caught on fire, it had a striking effect on how people thought about water quality. Today, with public water closures due to toxic blooms, shellfish and crab industries shut down creating food availability issues and financial impacts on communities, and large-scale fish kills washing up on our shores, we have perhaps finally found ourselves at a point where we need to make lasting changes to these failing systems. It will also be vital to ensure that policies designed to manage nutrient levels are updated to reflect a higher standard for water quality for both fresh and saltwater bodies. The new technologies of today each

[11] (Jianlong Wang, 2016)

present both pros and cons for how they address nitrogen removal in wastewater. One key takeaway from this research is that finding a solution to nutrient removal is not a one stop shop. There are many options available that may or may not work for every WWTP issue. It is also plausible that some combination of systems may need to be incorporated to be a long-term fix for effective wastewater cleanup.

Bibliography

Akshay Jain, Z. H. (2018). Cathode-enhanced wastewater treatment in bioelectrochemical systems. *Clean water*, 1-23.

Biological Nutrient Removal . (2021). Retrieved from Water online: https://www.wateronline.com/doc/biological-nutrient-0001

David Fowler, 1. M.-B. (2013). The global nitrogen cycle in the twenty-first century. *Philosophical Transactions of the Royal Society B*.

How a Burning River Helped Create the Clean Water Act. (2015). Retrieved from The Allegheny Front: https://www.alleghenyfront.org/how-a-burning-river-helped-create-the-clean-water-act/

How wastewater treatment works...the basics. (1998). Retrieved from United States Environmental Protection Agency: https://www3.epa.gov/npdes/pubs/bastre.pdf

Huijun Jia, Q. Y. (2016). Removal of nitrogen from wastewater using microalgae and microalgae–bacteria consortia. *Cogent Environmental Science*.

James N. Galloway, A. M. (2013). A chronology of human understanding of the nitrogen cycle. *Philosophical transactions B The royal society of London*, 368 (1621).

Jan Peter van der Hoek, R. D. (2018). Nitrogen Recovery from Wastewater: Possibilities, Competition with Other Resources, and Adaptation Pathways. *Sustainability*, 1-18.

Jianlong Wang, L. C. (2016). Biological nitrate removal from water and wastewater by solid-phase denitrification process. *Biotechnology Advances*, 1103-1112.

Jin Sun, H. C. (2020). Progress in Nitrogen Removal. *Processes*, 1-20.

Mohd Najibul Hasan, M. M. (2021). Recent technologies for nutrient removal and recovery from wastewaters: A review. *Chemosphere*, 130328.

National Service Center for Environmental Publications (NSCEP) - Primer for Municipal Wastewater Treatment Systems. (2004). Retrieved from United States Environmental Protection Agency: https://nepis.epa.gov/Exe/ZyNET.exe/20017KBE.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=

National Service Center for Environmental Publications (NSCEP). (2004). Retrieved from United States Environmental Protection Agency: https://nepis.epa.gov/Exe/ZyNET.exe/20017KBE.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=

NPDES Permit Basics. (2021). Retrieved from United States Environmental Protection Agency: https://www.epa.gov/npdes/npdes-permit-basics

ShadiRahimia, O. I. (2020). Technologies for biological removal and recovery of nitrogen from wastewater. *Biotechnology Advances*, Volume 43.

Xinning Zhang, B. B. (2020). Global Nitrogen Cycle: Critical Enzymes, Organisms, and Processes for Nitrogen Budgets and Dynamics. *National library of Medicine*, 120.