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REMOVAL OF NITROGEN FROM WASTEWATER (DENITRIFICATION)

The efficient removal of nitrogen from wastewater is a crucial imperative, driven by major concerns related to environmental preservation and public health protection. Nitrogen, in the form of nitrates and ammonia, exerts a significant influence on aquatic ecosystems and can pose serious risks to fauna, flora, and even human health.

In this InfoDBO, we will explore the essential reasons why the elimination of nitrogen from wastewater has become an undeniable priority, highlighting the environmental implications and potential threats to public health. We will also examine key biological processes, such as nitrification and denitrification, which play a central role in wastewater treatment to eliminate nitrogen, before concluding on the crucial importance of recirculation in this process, particularly in the context of solutions proposed by DBO International.

ENVIRONMENT

The removal of nitrogen from wastewater is of fundamental importance in preventing the eutrophication of lakes and drinking water sources, a harmful ecological phenomenon. When nitrogen, primarily in the form of nitrates and ammonia, enters aquatic ecosystems, it acts as a fertilizer, promoting excessive growth of algae and aquatic plants. This plant proliferation creates a dense layer on the surface, blocking sunlight and hindering the photosynthesis of submerged plants. Consequently, these plants decompose, consuming a significant amount of dissolved oxygen in the water. This process greatly reduces available oxygen levels, endangering the survival of fish and other aquatic organisms. "Dead zones," where aquatic life can no longer thrive, often result directly from this phenomenon. Thus, by eliminating nitrogen from wastewater, nutrient input into aquatic environments is controlled, preserving their ecological balance and preventing the degradation of these vital habitats.

Nitrogen, especially in the form of ammonia, is extremely toxic to aquatic fauna. Even at low concentrations, ammonia can cause significant harm to fish and other aquatic organisms. It primarily affects the gills of fish, impeding their ability to breathe and regulate the balance between saltwater and freshwater. This toxicity can lead to severe stress, decreased growth, impaired reproduction, and, in severe cases, death. Additionally, ammonia and nitrates can disrupt essential biological processes of aquatic organisms, affecting their ability to feed, reproduce, and maintain a healthy physiological balance. By removing nitrogen from wastewater, these risks are significantly reduced, contributing to the health and viability of aquatic ecosystems. This is particularly important in areas where treated wastewater is discharged into rivers, lakes, or estuaries, where it can have a direct impact on local fauna.

PUBLIC HEALTH

The presence of nitrates in drinking water, resulting from contamination by wastewater, poses a major risk to human health, especially for infants. Nitrates are converted into nitrites in the human body, and these can interfere with hemoglobin's ability to transport oxygen. In infants, this can lead to methemoglobinemia, or "blue baby syndrome," a potentially deadly condition characterized by decreased blood oxygenation. Symptoms include a bluish discoloration of the skin and breathing difficulties. Adults can also be affected, although less frequently. Furthermore, some studies suggest a link between prolonged exposure to high levels of nitrates and an increased risk of certain types of cancer, as well as other health problems. Therefore, treating wastewater to eliminate nitrogen is essential to ensure the safety of drinking water and protect public health.

Nitrates from wastewater can seep into the soil and contaminate groundwater, a major source of drinking water for many communities. This contamination poses a serious risk to human health, as mentioned earlier, and can also have economic implications, as treating nitrate-contaminated water is expensive and complex. Additionally, once nitrates are present in groundwater, they are challenging to eliminate. They can persist for long periods, extending the risk of contamination well beyond the initial source. Therefore, effectively treating wastewater to remove nitrogen before it is discharged into the environment is an essential preventive measure to protect groundwater resources and ensure the availability of safe drinking water for current and future generations.

TREATMENT

Nitrification and denitrification are two key biological processes in wastewater treatment, especially for the removal of nitrogen, a major pollutant.

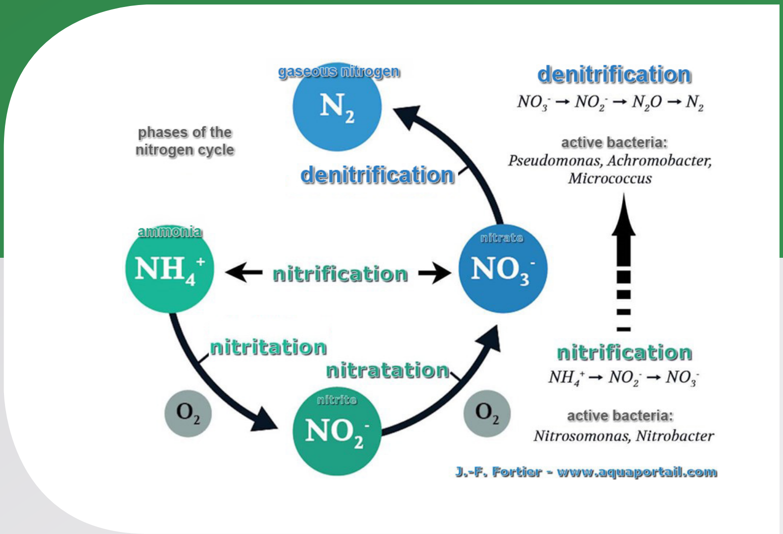

Figure 1: Nitrogen Cycle (Fortier, 2006)

NITRIFICATION

Nitrification is an aerobic (requiring oxygen) process where nitrifying bacteria convert ammonia (NH_3) into nitrites (NO_2^-) and then into nitrates (NO_3^-). The process occurs in two stages: the oxidation of ammonia into nitrites and the conversion of nitrites into nitrates. Both stages take place as wastewater passes through DBO International treatment systems.

$$\underset{\text{ammonium}}{NH_4^+} \rightleftharpoons \underset{\text{nitrite}}{NO_2^-} \rightleftharpoons \underset{\text{nitrate}}{NO_3^-} \quad (3)$$

$$\underset{\text{ammonium}}{2NH_4^+} + \underset{\text{oxygen}}{3O_2} \longrightarrow \underset{\text{nitrite}}{2NO_2^-} + \underset{\text{water}}{2H_2O} + \underset{\text{hydrogen}}{4H^+} \quad (4)$$

$$\underset{\text{nitrite}}{2NO_2^-} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{nitrate}}{2NO_3^-} \quad (5)$$

Figure 2: Nitrification Formulas (Bourque, 1997)

Three categories of organisms are responsible for transforming ammonia into nitrite: ammonia-oxidizing bacteria, ammonia-oxidizing archaea, and nitrite-oxidizing bacteria. The bacteria oxidizing nitrites and the archaea oxidizing ammonia exhibit notable similarities. Ammonia-oxidizing bacteria are mainly found among beta-proteobacteria and gamma-proteobacteria. So far, two species of ammonia-oxidizing archaea have been isolated and characterized: Nitrosopumilus maritimus and Nitrososphaera viennensis. In soils, the most frequently studied ammonia-oxidizing bacteria belong to the genera Nitrosomonas and Nitrosococcus. Although in soils, both ammonia-oxidizing bacteria and ammonia-oxidizing archaea contribute to ammonia oxidation, it has been observed that ammonia-oxidizing archaea are more dominant in soils and marine environments. This dominance suggests that archaea from the Thaumarchaeota group may play a more significant role in the ammonia oxidation process in these environments.

The transformation of nitrite into nitrate, constituting the second phase of nitrification, is mainly carried out by bacteria belonging to the genera Nitrobacter and Nitrospira. This step, like the first, generates energy that is then used to synthesize ATP. Organisms involved in nitrification are chemolithoautotrophs, using carbon dioxide as a carbon source for their growth. Some ammonia-oxidizing bacteria possess the enzyme urease, which facilitates the decomposition of urea into two molecules of ammonia and one molecule of carbon dioxide. It has been observed that Nitrosomonas europaea, along with other populations of ammonia-oxidizing bacteria in the soil, use the carbon dioxide produced by this reaction to generate biomass via the Calvin cycle. Simultaneously, they capture energy by converting ammonia (the other product of urease) into nitrite. This capability could explain why ammonia-oxidizing bacteria experience increased growth in the presence of urea, especially in acidic environments.

In the field of ecology, nitrifying bacteria form a specific taxonomic group and are particularly abundant in ammonia-rich environments, such as areas with high protein decomposition and wastewater treatment plants. These bacteria thrive in the waters of lakes and rivers, especially where there is a significant input of wastewater. Their proliferation in these environments is favored by the high concentration of ammonia in wastewater and freshwater.

In System O)) (Enviro))septic), ammonia-oxidizing bacteria present in wastewater and various microorganisms in the surrounding soil contribute to the nitrification process.

DENITRIFICATION

Denitrification is an anaerobic process (occurring in the absence of oxygen) where denitrifying bacteria convert nitrates into nitrogen gas (N_2) or nitrous oxides. The process occurs in two stages: the reduction of nitrates and the release of nitrogen gas.

$$\underset{\text{nitrate}}{4NO_3^-} + \underset{\text{organic material}}{5\{CH_2O\}} + \underset{\text{hydrogen}}{4H^+} \longrightarrow \underset{\text{nitrogen (gas)}}{2N_2(g)} + \underset{\text{carbon dioxide}}{5CO_2(g)} + \underset{\text{water}}{7H_2O} \quad (6)$$

Figure 3: Denitrification Formula (Bourque, 1997)

The oxidation of organic or inorganic substances involves the transfer of electrons (e-) or resulting hydrogen (H), which is carried by an electron and hydrogen carrier that varies depending on different enzymes and bacteria. Generally, cytochromes and quinones serve as carriers of electrons or hydrogen. Electron transport leads to the synthesis of ATP through chemiosmotic coupling and, consequently, the conservation of energy. In addition to N2, however, a smaller amount of nitrous oxide (gaseous) is released as an intermediate. This process occurs in nature wherever nitrate and denitrifiable, oxidizable organic matter are available under anoxic or hypoxic conditions (e.g., in swamps, soils, sediments in rivers and lakes).

Some bacteria can also contain molecular hydrogen H2, hydrogen sulfide H2S, ammonium NH4+, ferrous ions Fe2+, and methane. These components, along with nitrate NO3-, are oxidized to form molecular nitrogen N2. Nitrogen gas is then released into the atmosphere through gas diffusion.

IN CONCLUSION

That's why it's crucial to have a recirculation process to completely remove nitrogen from wastewater. During recirculation, nitrates are returned to the primary tank, where they are exposed to numerous denitrifying bacteria in anaerobic conditions, thus promoting their conversion into nitrogen gas. Our engineering team at DBO International has the necessary expertise to calculate the percentage of water that needs to be recirculated to meet the requirements of each country. This will ensure achieving the expected efficiency and maintaining the purification performance level for many years.

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