Comparison of treatment technologies for highly concentrated nitrogen compound wastewater

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Abstract. The flow of biogenic elements with wastewater into water bodies leads to an increase in the content of biogenic and organic compounds, a decrease in the oxygen content, the appearance of anaerobic zones, an increase in water turbidity, discoloration, pollution with microorganisms, including pathogenic ones, so the research area was the methods of treating wastewater that is highly loaded with nitrogen. Anammox process was considered as the most promising method of treating wastewater highly concentrated on nitrogen compounds. The analysis of the main existing technologies is carried out, the advantages, disadvantages and features of the application (operation) of these methods are revealed. The treatment of return streams as an alternative to the classical solution and an effective tool for improving the quality of wastewater treatment from nutrients is considered. The experience of implementation and operation of Anammox process at aeration stations in different countries is described.

Keywords: Anammox, AnitaMox, Sharon – Anammox, Demon, CANON.

1 Introduction

Biogenic compounds, such as nitrogen and phosphorus, can enter surface waters both naturally (leaching from the topsoil, precipitation, various processes in the water body itself) and as a man – made factor as the discharge of wastewater from industrial, domestic and agricultural facilities, etc.

Exceeding the maximum permissible concentration (MPC) when biogenic elements fall into water bodies can lead to an eutrophication process. This leads to environmental changes, deterioration, accompanied by adverse effects on water use for human consumption and other various purposes.

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According to the Federal State Statistics Service, the intake of nitrates with wastewater into water bodies from 1993 to 2021 increased from 140 thousand tons to 360 thousand tons per year. It there was an increase of 2.5 times. At the same time, the volume of wastewater discharge decreased from 68.2 billion m^3 to 35.5 billion m^3. That is, even with a decrease in the volume of discharge, there was an increase in both flow into water bodies. In other words, there is a problem of deterioration and decrease in the quality of wastewater treatment from nutrients [1].

At aeration stations with anaerobic sludge fermentation, after its dehydration, about 15-20% of the total nitrogen load returns back to the water treatment plant.

Thus, in order to reduce the load on treatment plants and improve the quality of wastewater treatment from biogenic compounds, it is important to introduce into the technological schemes the stage of processing return flows after the stage of sludge dewatering [2].

The aim of the work is to analyze the existing methods of treatment of highly nitrogen-concentrated wastewater in order to identify the most promising.

2 Materials and methods

Currently among the methods of biological purification from ammonium nitrogen, the most promising are Anammox technologies. According to the information and technical reference book of the best available technologies (BAT) in the field of wastewater treatment, the Anammox process is a "promising technology" for the removal of ammonium nitrogen as well as it provides an environmental effect commensurate with BAT, while being more economical [3].

The Anammox (Anaerobic Ammonium Oxidation) process is a biological process in which ammonia and nitrates are oxidized without oxygen. A group of microorganisms - planktomycetes, carries out this process. Anammox bacteria are anaerobes, and receive energy by oxidizing ammonium in the absence of oxygen.

The Anammox process is the most modern technology for removing nitrogen from wastewater. It has been used since the beginning of the XXI century.

It consists in the fact that:

1. half of the ammonium is oxidized to nitrite by bacteria-nitrifiers of the first stage (the first subprocess),

$$2NH_3 + 3O_2 \rightarrow 2HNO_2 + 2H_2O$$

2. the remaining half of the ammonium is oxidized by this nitrite to form nitrogen gas (the second sub-process).

$$NO_2^- + NH_4^+ \rightarrow N_2 + 2H_2O$$

The second process is key, the most important as it is carries out by the unique Anammox bacteria in strictly anaerobic conditions (without access to oxygen). The Anammox process is economical and energy efficient, consumes 60% less oxygen. The ammonium removal efficiency reaches 90% and the formation of sediment is reduced by 15-20 times compared to traditional nitri/denitrification technology, no organic substrate is required for denitrification. As a result, the cost of nitrogen removal compared to classical nitri-/denitrification is 2–3 times lower (according to European data, nitri/denitrification costs 2.3–4.5 euros/kg of nitrogen, the Anammox process: 0.7–1.1 euros/kg of nitrogen) [4]-[6].

The Anammox process requires a certain level of alkalinity (pH) for optimal growth and metabolism of the bacteria that carry out this process. Typically, the optimal pH for Anammox is in the range of 7.5 to 8.5. The optimum temperature for the Anammox process is typically between 30 and 40 °C. However, this process can occur at lower temperatures (from 20 to 25 °C), while the activity of Anammox bacteria decreases, and therefore the rate of oxidation of ammonium nitrogen decreases.

There are several variants (more than 10 in total) of Anammox technologies, differing in the following main criteria:

- conducting the two subprocesses described above in a single reactor or in two different ones;
- hydraulic mode - flow-through reactors, or cyclic action (the so-called SBR-reactors);
- method of retaining the biomass of bacteria (activated sludge) Anammox: in the form of free-floating granular sludge or attached sludge on a loading material.
- The main technologies used include:
- Sharon - Anammox (two-reactor technology with a constant or fractional supply of purified liquid and using free-floating sludge);
- Canon (single-reactor flow action with flocculated sludge);
- Demon (single-reactor periodic action with flocculated sludge);
- Anita-Mox (single-reactor flowing with sludge attached to the floating loading material. Can be used both with free-floating sludge and without it) [7]-[8].

3 Discussion

As a result of the study, based on the analysis of scientific works, literature and experience of foreign representatives, a comparison of the main applied technologies for the treatment of nitrogen-enriched wastewater was carried out. Their advantages and disadvantages were identified, as well as the most promising technology for implementation at existing aeration stations was determined.

The first technological scheme implemented at the treatment facilities using the Anammox process was the SHARON-ANAMMOX technology, was developed at the Delft University of Technology and subsequently launched at the Dokhaven aeration station, Utrecht (Netherlands) to clean wastewater return flow. The technology allows to return up to 80% of ammonium nitrogen at a workload of 1.2 $kgN\ (m^3 \bullet day)$ [9].

The SHARON – ANAMMOX technological system includes two stages. First, in the SHARON reactor, part of the ammonium is oxidized to nitrite under aerobic conditions. At the next stage, the resulting mixture of nitrite and ammonium enters ANAMMOX reactor to convert into molecular nitrogen. The disadvantage of SHARON-ANAMMOX technology is the need to maintain a temperature regime of about 35 C° and control the conditions (pH 7-8, the dose of dissolved O_2) under which we define an increment of ammonium-oxidizing bacteria only.

Anita-Mox technology (ANITAMox) was developed based on an Anammox process for the treatment of effluents with a high content of ammonium and low organic matter (return flows from the treatment of fermented sludge, etc.). The advantages of using this technology in comparison with other methods of purification of highly nitrogen-concentrated wastewater include:

- the use of loading material, floating plastic elements mobile in the reactor volume to retain the biomass of Anammox bacteria. The growth of these bacteria, in a purified culture, is very slow, the time of cell division (doubling) occurs in a time equal to at least ten days. Therefore, to reduce the unwanted removal of biomass from the reactor, their tendency to attach growth and the formation of biofilms on the loading material was used. This is an attempt to solve one of the main problems associated with the technology of the Anammox process. Also, the use of loading allows us to reduce the sensitivity of the process to toxins;
- the ability to modify the technology and additionally use free-floating sludge, increases the efficiency and reliability of the process. In this case according to the developers, the effectiveness of ammonium removal reaches 95%;
- the smallest / minimum amount of excess sediment - as a result of the use of biofilm;
- the use of BioFarm is a special development strategy for the rapid start of the technological process. Due to the slow growth rate of Anammox bacteria, it takes 9-18 months to launch the technology. The long start-up time of Anammox reactors seriously limits the application of the process, but this drawback can be eliminated by applying the concept of BioFarms, for the rapid launch of new installations, which significantly reduces the initial phase - up to 2-5 months [10]-[11].

The volumetric capacity for nitrogen, for this technology, is on average 1 - 1.2 *kgN* $(m^3 \cdot day)$.

In 2011, a project was implemented in Växjö (Sweden) to introduce the innovative AnitaMox technology into an existing aeration plant in order to improve the efficiency of nitrogen removal at treatment plants. To introduce the Anammox process, the SBR reactor was reconstructed and biomass carriers were introduced. The actively used volume of the tank corresponded to a filling level of 53%. The start-up and operation of the full-scale process was controlled by NH_4, NO_3, dissolved oxygen and pH sensors, online. A new real-time aeration management strategy has been developed to improve energy efficiency.

Upon reaching its design capacity a few months after launch, the nitrogen removal efficiency of the AnitaMox process was over 90%. It was possible to achieve a high level of nitrogen removal while reducing energy consumption and the absence of carbon sources from the outside.

CANON's technology was first launched in Austria as an industrial plant providing aerobic and anaerobic processes in a single reactor. The unit receives return wastewater characterized by an $N\text{-}NH_4 / COD_{ratio} = 2.5\text{-}3$. The nitrification process takes place in a sequential cyclic reactor with variable aeration. Regulation of the oxygen supply to the reactor is carried out by controlling the pH level. The volumetric rate of nitrogen removal is 810 *gN* $(m^3 \cdot day)$.

In Zurich (Switzerland), a CANON technology unit for the purification of silt water from nitrogen pollution operates at the city sewage treatment plants. It consists of two sequencing batch reactors (SBR), equipped with pH control device. The reactors process partial anammox nitrification at a temperature of 25-30 °C. The nitrogen removal rate is

0.6 *kgN* $(m^3 \cdot day)$ in a 500 m^3 reactor and 0.4 *kgN* $(m^3 \cdot day)$ in a 400 m^3 reactor. The oxygen supply was regulated by controlling the pH [12] – [18].

The disadvantage of CANON technology is that the process requires precise control of the nitrogen load and the amount of oxygen in the water. The gravity separator, which is used to selectively retain the granules of Anammox bacteria, requires control of the flow rate of supply of a new portion of into the SBR reactor otherwise the hard-to-grow useful biomass of the anammox granules will be removed from the system.

In 2011, DEMON technology was introduced at the Chambers Creek Wastewater Treatment Plant (USA) to reduce nitrogen discharge to reduce the operating costs. The detailed design and construction began. On the ground of collected results of a four-month pilot study system test. The average work-load is 750 $gN\ (m^3 \bullet day)$. The system was launched in August 2017 and can remove about 80% of ammonia. This is an equivalent to reducing the supply of nitrogen to Puget Sound bay by more than 400 tons per year [19].

A feature of the DEMON technology is that the retention and return of Anammox bacteria occurs through the use of a special device - hydrocyclone or cyclonic separator. The main advantages of the technology include the fact that the cost of complete nitrogen removal is one of the lowest, as well as the possibility of implementing the technology when upgrading existing tanks. The disadvantage of the technology is the strict control of parameters and compliance with a number of conditions (pH, O_2 concentration and processing time) [20]-[23].

4 Conclusions

Thus, differences between existing technologies for the treatment of highly nitrogen-concentrated wastewater should be taken into account when assessing the best technology for specific plants and enterprises. However, ANITAMox technology based on the Anammox process is a cost-effective and energy-saving solution and has great potential for implementation.

It is recommended to start from this technology when looking for further ways to optimize the processes of cleaning return flows in order to reduce operating costs, increase system stability and efficiency of treatment facilities.

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