Innovative technologies in municipal wastewater treatment plants in Sweden to improve Baltic Sea water quality

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Abstract. The article presents new trends in the treatment of municipal wastewater in Sweden caused by the constantly increasing requirements for discharging pollutants into Baltic Sea waters. The development of new technologies for nitrogen removal, pharmaceutical residues removal and the possibility of using membrane processes in wastewater treatment is presented. The state of research on innovative wastewater treatment processes at the level of pilot-scale tests and their implementation in full technical scale has been described. These technologies can allow the application of new, economical and environmentally friendly wastewater treatment processes based on biological, chemical and physical methods. Swedish wastewater treatment plants are preparing to meet the new conditions required for discharged wastewater with a value of 6 mg N/L for total nitrogen and 0.2 mg P/L for total phosphorus. This requires large investments in the reconstruction of municipal wastewater treatment plants and the introduction of new treatment processes.

1 Introduction

The Baltic Sea is a common recipient of wastewater discharged from 9 countries, including Poland and Sweden. Hence the common concern for the protection of Baltic Sea waters and the cooperation with the exchange of experience between these countries. The development of new innovative technologies will make it possible to meet the increasing requirements for environmental protection, including stringent requirements for the removal of nutrients: nitrogen and phosphorus, as well as organic material.

The article presents the directions in development of new technologies in wastewater treatment in Sweden. Their implementation will allow for more efficient removal of pollutants and will improve the economic aspects of treatment aimed at an energy self-sufficient municipal wastewater treatment plants (WWTPs).

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2 New technologies in Swedish municipal wastewater treatment plants

New technologies to increase the efficiency of nitrogen removal, which are currently being tested both at pilot-scale and on a full technical scale in Sweden, are based on the application of anammox bacteria. Such processes are used both for the treatment of reject water after the dewatering of digested sludge and for mainstream treatment [1].

Another tested technique for nitrogen removal is based on an aerated membrane bioreactor with a layer of biofilm, the so-called Membrane Aerated Biofilm Reactor (MABR).

The removal of pharmaceutical residues from wastewater using ozone and activated carbon is a challenge not only for Sweden, but also for many European countries.

Another technological innovation is the introduction of membrane techniques for wastewater treatment. Pilot studies are currently being carried out on the implementation of Membrane Biological Reactor MBR at Henriksdal WWTP which is Stockholm's largest WWTP. It will be the largest membrane installation in the world on a full technical scale.

Research on increased biogas production and nutrient recovery is also being carried out extensively in many wastewater treatment plants.

3 Urban wastewater treatment in Sweden - historical background and current challenges

The development of wastewater treatment in Sweden is shown in Fig. 1. Almost 98% of wastewater is discharged into sewerage systems in Sweden.

In the 1960s, biological treatment was introduced, which resulted in a significant reduction in the amount of organic compounds discharged into the Baltic Sea, as shown in Fig. 2.

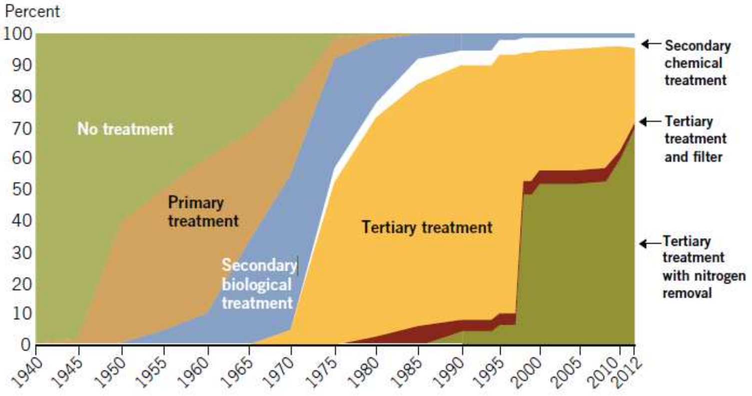

Fig. 1. Urban wastewater treatment status in Sweden [2].

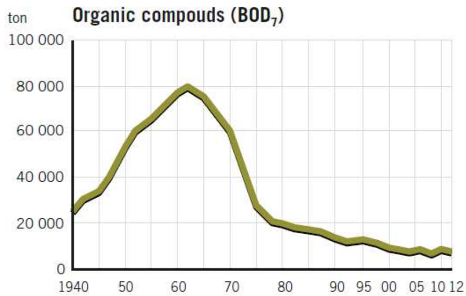

Fig. 2. Quantities of organic material discharged from Swedish wastewater treatment plants into the Baltic Sea between 1940 and 2012 [2].

Sweden was one of the first countries in the world to introduce phosphorus removal in the 1970s, which resulted in a drastic reduction of its load into the waters of the Baltic Sea. At the end of the 1980s and in the 1990s, nitrogen removal technologies were introduced, which resulted in a reduction of nitrogen loads discharged into the Baltic Sea (Fig. 3).

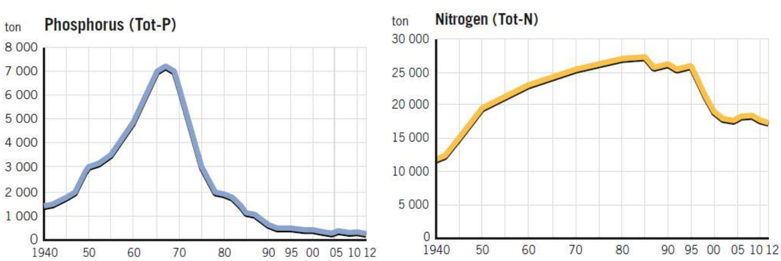

Fig. 3. Phosphorus and nitrogen discharges from Swedish wastewater treatment plants into the Baltic Sea [2].

Currently, Swedish wastewater treatment plants are preparing for stricter requirements for nitrogen and phosphorus removal, which aim to reduce the load of these nutrients discharged into the Baltic Sea. In order to meet these requirements, the Baltic Sea Action Plan [3] was developed, which in 2009 proposed 3 alternatives for nitrogen removal for wastewater treatment plants with more than 2,000 p.e :

1. treatment plants which do not have nitrogen removal will introduce 70% nitrogen removal,
2. treatment plants with nitrogen removal shall achieve 80% N removal by increasing the amount of external organic material added and by increasing the recirculation of wastewater after the nitrification process,
3. treatment plants will reach 6 mg/L of total nitrogen at the outlet (requirements correction in 2013).

And 2 alternatives for phosphorus removal:

1. treatment plants reach 0.2 mg P/L at the outlet (by precipitation and post-chemical precipitation, which is associated with increased consumption of chemicals),
2. treatment plants reach 0,1 mg P/L at the outlet (through filtration).

4 Innovative nitrogen removal technologie

To meet the nitrogen removal requirements, the treatment of reject water after the dewatering of digested sludge using the Anammox process is introduced. Reject water is characterized by high concentrations of NH_4-N (about 1000-1500 mg N/L) and high temperature (about 30ºC). The removal of nitrogen from the side stream results in a reduction of about 15-20% of the N load delivered to the biological processes of the wastewater treatment plant [4, 5]. Currently, 5 plants in Sweden are removing nitrogen from reject water using the Anammox process, and next are planned. Both technologies are based on biofilm with Kaldnes carriers (process DeAmmon with K1 carriers, AnitaMox with K5 carriers) and based on granulated sludge (process DEMON) were introduced at Swedish wastewater treatment plants.

Studies on the application of the Anammox process in the mainstream, which is characterised by low NH_4-N concentrations of about 40-50 mg N/L, low temperatures of about 12-15°C (in winter) are carried out at 2 pilot-scale plants in Stockholm and Malmö. [5].

5 Membrane technology

Another solution for nitrogen removal is the use of membrane aerated biofilm reactors. At the Eskilstuna wastewater treatment plant, the hybrid system based on ZeeLung® MABR, where bacteria in biofilm on the membrane work together with bacteria in the activated sludge to remove organic compounds and nutrients was tested at pilot-scale. This solution allows the WWTP to be upgraded and adapted to the new requirements within the existing reactors and with minimal additional energy. In combination with energy recovery from sludge, this can be a step towards achieving an energy neutral wastewater treatment plant.

The results obtained during first 6 months of the test were: 94.3% of average NH_4-N removal efficiency, 40% of average Tot-N removal efficiency with maximum value of 59% Tot-N removal efficiency [6]. MABR with a layer of biofilm with oxygen transport through the membrane to the biofilm, where oxidation of contaminants supplied from the membrane surface takes place, are illustrated in Fig. 4.

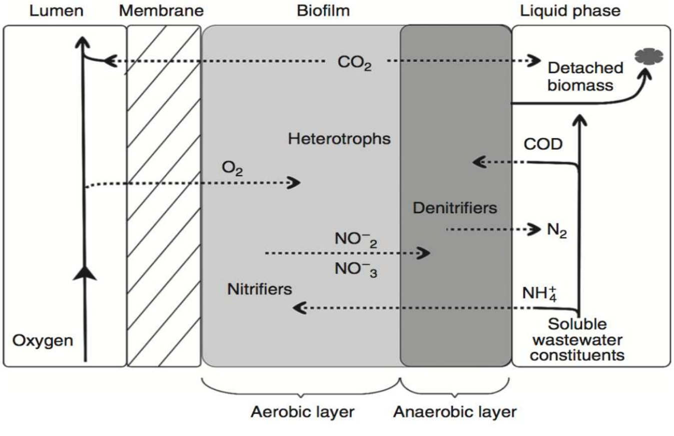

Fig. 4. Nitrogen transformation in MABR [7].

6 Removal of pharmaceuticals

The next step in introducing innovative technologies at Swedish wastewater treatment plants will be to use new methods to remove the residuals of pharmaceuticals and other chemicals. Sweden is preparing to introduce new expected legislation in the European Union on the disposal of pharmaceuticals.

A number of research projects are currently being carried out in which various technological processes are being tested. Figure 5 shows the potential for applying different technologies now and in the future [8]. Technologies for the removal of pharmaceuticals can be integrated into the main wastewater treatment line or after conventional treatment processes. Currently, the following processes are being tested: mechanical (ultrafiltration, reverse osmosis, nanofiltration), ultrasonic (ozonation), biological (active filters and enzymes), adsorption (activated carbon) and combinations of these processes. New technologies of removing pharmaceuticals are shown in Fig. 5.

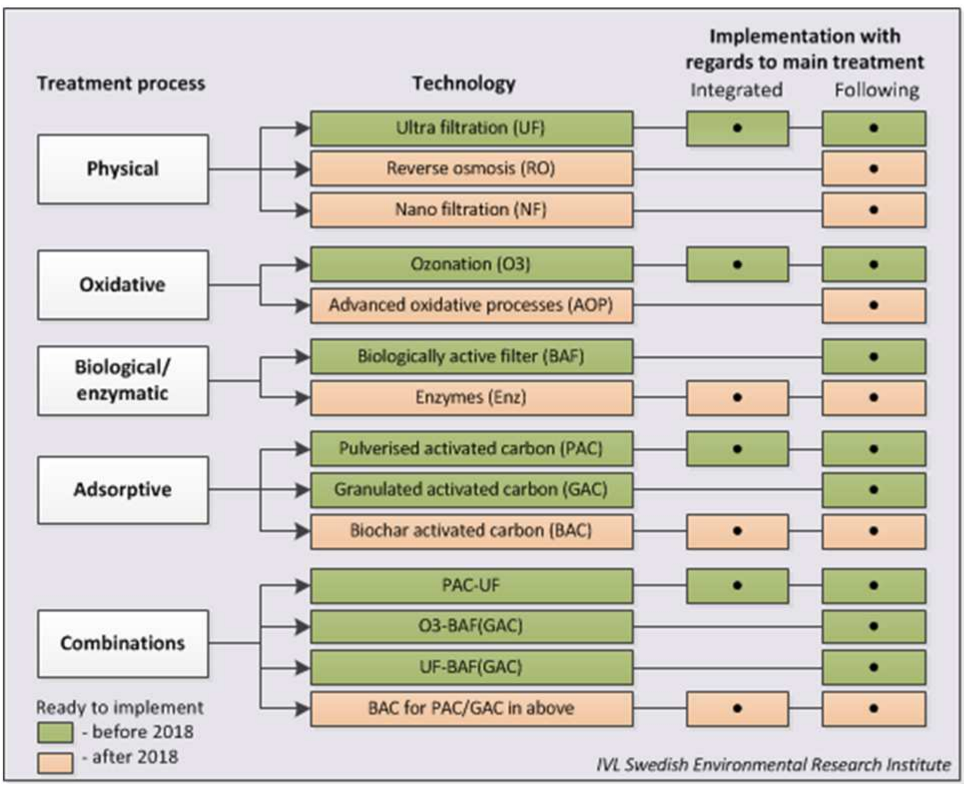

Fig. 5. New technologies for removing pharmaceuticals [8].

Although no requirements for the disposal of pharmaceuticals have yet been introduced in Sweden, ozone has been applied after several years of testing at the Linköping treatment plant. Parameters of the Nykvarnsverket wastewater treatment plant in Linköping are: 180.000 p.e., flow rate 40.000 m^3/d. The parameters of the ozonization reactor are: flow 1500-2000 m^3/d, reactor capacity 600 m^3, dosage 4-8 g O_3/m^3, hydraulic retention time 12 minutes.

The process of removing pharmaceuticals will soon be launched at the Knivsta wastewater treatment plant, where pilot-scale studies are widely conducted [9]. Different methods for the removal of pharmaceutical residues have been tested, but many studies confirm that the combination of ozone and granular activated carbon (GAC) gives the best results.

If these new advanced technologies were used to remove pharmaceutical residues from 45 of the largest wastewater treatment plants around the Baltic Sea, the discharge of these substances from the plants into the sea would be reduced by 50% [10]. This is illustrated in Fig. 6.

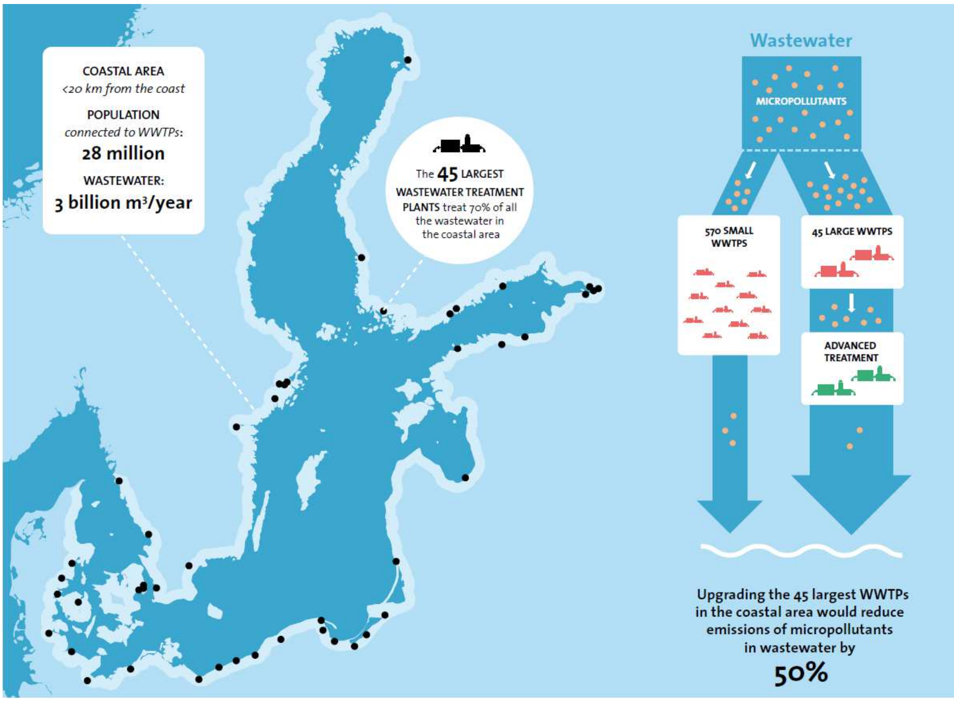

Fig. 6. Large coastal wastewater treatment plants discharging wastewater into the Baltic Sea [10].

7 Summary

Large wastewater treatment plants along the Baltic Sea coast (in the Malmö and Stockholm regions) already have stringent requirements for phosphorus of 0.3 mg P/L and in order to achieve this, filtration is used as the last stage of treatment. Therefore, reaching the value of 0.2 mg P/L is not a big problem with the widely used method of chemical precipitation for P removal.

In order to meet the new expected requirements of 6 mg/l for nitrogen in the effluent from WWTPs sidestream treatment of reject water using the Anammox process is introduced. The application of partial nitritation/anammox process for mainstream is still a challenge. The use of membrane aerated biofilm reactors MABR in combination with energy recovery from sludge can be also a step towards achieving an energy neutral wastewater treatment plant in future.

Many different processes have been tested for pharmaceutical residues removal but no requirements for their disposal have yet been introduced in Sweden.

The introduction of innovative technologies for phosphorus, nitrogen and pharmaceutical residues will enable the modernisation of WWTPs and their adaptation to new regulations. Reconstruction of the existing reactors or supplementing the technology with new processes requires large investments.

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