PRESENT AND FUTURE DIRECTIONS IN SWEDISH RESEARCH ON WASTEWATER HANDLING

E. Plaza and J. Trela

Department of Land and Water Resources Engineering, Royal Institutre of Technology, KTH, Brinellvägen 32, S-100 44 Stockholm, Sweden
(E-mail: *elap@kth.se, trela@kth.se)*

Abstract Research activities in Sweden related to wastewater handling have been focused on optimizing the built systems and the development of new methods. A change in research priorities has gradually occurred in order to comply with sustainability principles. At present new technologies should meet requirements of sustainable development and multi-disciplinary approach is applied. Recent results from research on nitrogen removal with Anammox process application are presented. The application of membrane bioreactor system followed by granular activated carbon filtration was studied as the efficient technology for removal of pharmaceutical compounds. Future main research areas in wastewater handling planned to be investigated in Sweden are specified.

Keywords: Anammox, Nitrogen removal, Pharmaceutical compounds, Research, Sweden, wastewater

INTRODUCTION.

Water and wastewater handling may be performed in many ways including local or central systems, separated and non-separated systems, nature based or technical methods for treatment. Independent of the choice of system these should comply with certain principles and goals. These may be summarized as three basic goals:

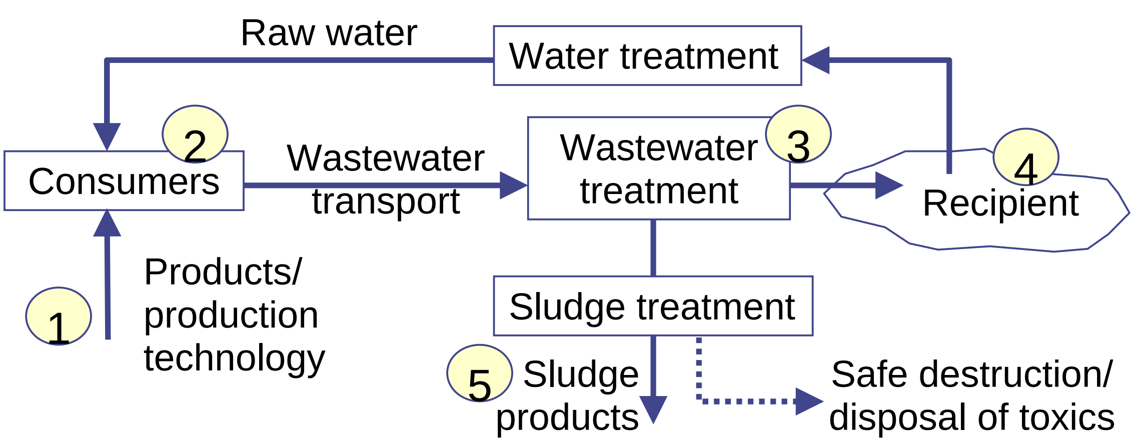
1. Extracted raw water should be seen as a ”loan” that after use should be returned to nature with equal quality
2. Thou shalt not waste; resources in wastewater should be recovered and recycled and harmful substances destroyed or deposited in a safe way
3. Sustainable development principles should be applied to meet present needs without compromising next generations needs i.e. low use of non-recoverable resources.

Research activities related to water and wastewater handling have in general been focused on solving the different problems due to contamination of groundwater, lake and the marine environment (Hultman, 2007). Focus has been given on specific problem and with a change every 20 years (Table 1),

Table 1. Changes in priorities of wastewater treatment in Sweden

TIME	MAIN PROBLEM	REMEDIES
From 1930	Visible pollutants	Mechanical treatment
From 1950	Low oxygen contents in recipient	Secondary/biological treatment
From 1970	Eutrophication of lakes	Tertiary/chemical treatment
From 1990	Marine eutrophication	Removal of nitrogen/phosphorus
Present and future From 2010 (predicted)	Recovery of resources (as phosphorus and energy) Deposition of sludge "Unwanted substances" in aquatic environment (pharmaceuticals, synthetic chemicals, hormones New unknown??	Eco-cycling, Implementation of Agenda 21, Sustainable technologies, Modified sludge handling, Increased public participation/responsibility, Development of new wastewater treatment technologies (Anammox etc)

At present a change in research priorities can be observed and new technologies should meet requirements of sustainable development. and multi-disciplinary approach is applied (Figure 1).



1. Production technology: Safe personal care products, pharmaceuticals and drugs
2. Communication: Interactions between consumers, water companies, etc.
3. Technology development: Membrane, removal of microorganics, deammonification, phosphorus recovery, etc.
4. Recipient effects: New threats
5. Resources recovery: phosphorus recovery

Figure 1. Multi-disciplinary approach in water and wastewater treatment

INNOVATIVE TECHNOLOGIES FOR WASTEWATER TREATMENT

Anammox application for treatment of wastewater with high nitrogen content.
Himmerfjärden wastewater treatment plant (SYVAB) and the Royal Institute of Technology (KTH) has been cooperated in developing a cost-effective treatment method (deammonification) to remove nitrogen from supernatant obtained from dewatering of digested sludge. Experiments have been performed in a pilot plant built by PURAC AB. Deammonification is a two-step process. In a first step about half of the influent ammonium nitrogen is oxidized to nitrite nitrogen and is followed by a reaction between formed nitrite with remaining ammonium to nitrogen gas (anammox). Four full-scale plants are in operation in Europe (Rotterdamin in Holland, Hattingen in Germany, Strass in Austria, Stockholm in Sweden).

In comparison with traditional technology with nitrification and denitrification deammonification only requires about 38 % of oxygen supply (oxidation of half ammonium amount to nitrite) and no organic material is needed for nitrogen gas formation. This results in large possibilities for savings in operational costs.

Both two-step technology with separate reactors for partial nitritation and anammox proces. and one-step technology with one reactor has been studied. Kaldnes rings were used as support material for bacteria forming a biofilm (Cema 2006, 2007; Szatkowska 2007, 2006, 2005). In the case of one-step technology anammox bacteria formed an inner layer of the biofilm and nitritation bacteria an outer layer.

Two-stage technology could be performed as a stable process and could be monitored by use of pH and conductivity measurements. A decrease of pH value by 1.2 units gave a quotient between nitrite nitrogen and ammonium nitrogen of 1.3 that is a suitable ratio for the following anammox process. The pH decrease could be obtained at an oxygen level of about 1.2 g O_2 m^{-3}. Conductivity measurements were well correlated with influent and effluent nitrogen concentrations and removed nitrogen both in the nitritation and anammox reactors. About 500 g N m^{-3} could be removed totally from the two-stage system corresponding to about 80 % removal efficiency (Gut 2007, 2006).

From July 2005 the operation was changed in the nitritation reactor to single sludge technology (Figure 2) that in a short time could be established due to seeding of anammox bacteria from the second reactor. The outer layer with nitritation bacteria supplied the inner layer of anammox bacteria with nitrite. The effluent nitrite concentration was very low despite rather high values of ammonium. The nitritation reaction was the rate limiting step for deammonification which also was confirmed by batch studies. An extra volume is therefore not needed for the anammox process and deammonification can be performed in one stage.

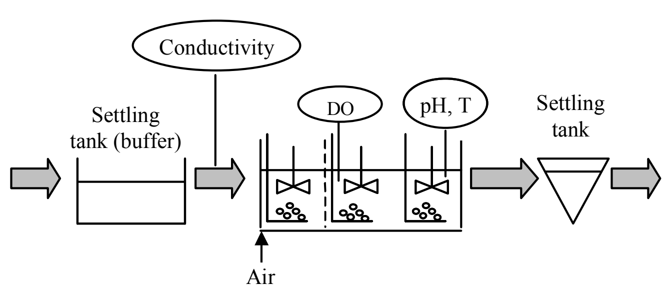


Figure 2. Flow diagram of the pilot-plant with one-stage partial nitritation and Anammox processes

Promising results were obtained with a removed nitrogen of about 1.5 g N m^{-2} d^{-1} (corresponding to 15 g N m^{-3} h^{-1}) and results are presented in Figure 3. The nitrogen removal varied between 33 and 90 % with 1 day hydraulic residence time and an influent ammonium concentration between 360 and 945 g N m^{-3}. During the operational period about 41.2 g $m^{-3}$of nitrates was produced, what was around 11.1% of the removed ammonium nitrogen. This value is very close to a stoichiometric one which is equal to 11%. In the Figure 4 nitrogen variations and the process efficiency in the partial nitritation/Anammox process are shown. The process could be monitored by pH and conductivity measurements.

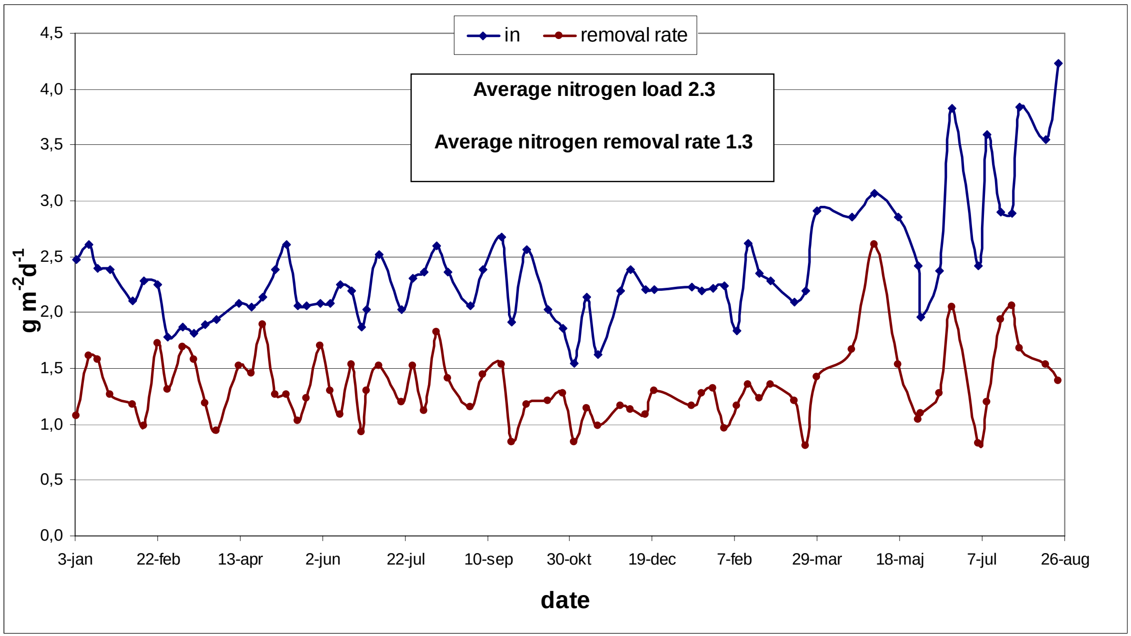


Figure 3. The nitrogen load and removal rate

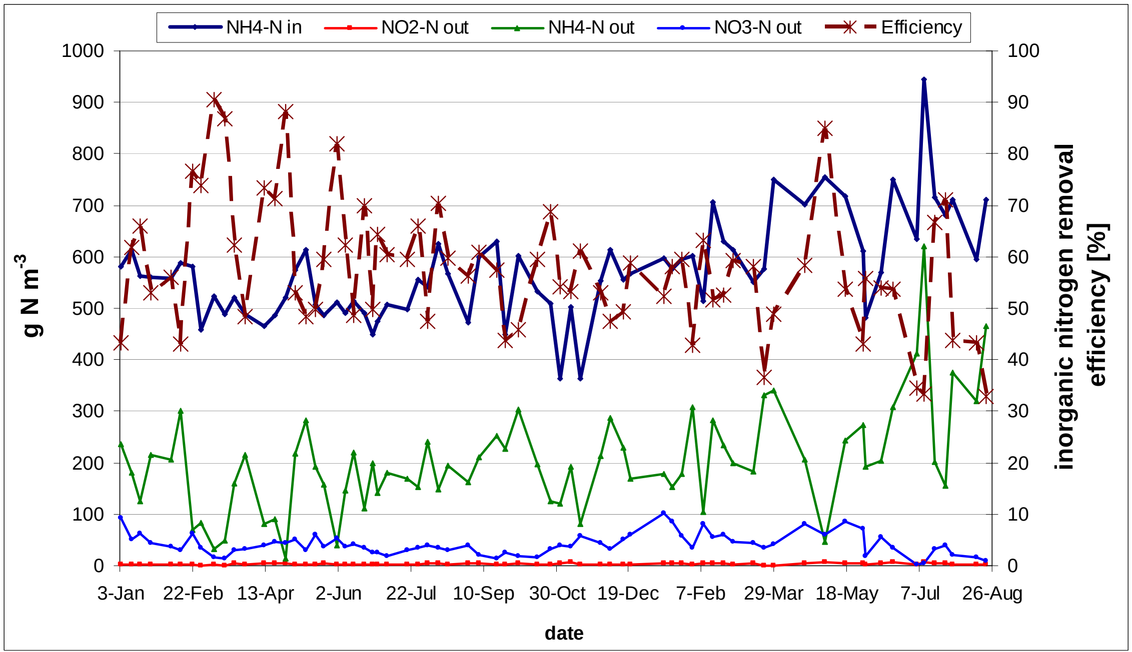


Figure 4. Nitrogen variations and the process efficiency in the partial nitritation/Anammox process

Table 2. Removal efficiency for metoprolol, carbamazepine and naproxen with application of MBR and GAC. (Dlugolecka et al., 2007)

	Target compound	Concentration [mg g^{-1} MLSS]	% of removal MBR	% of removal MBR + GAC
Series 1 [1.8 MLSS]	MET	6.11	7.4	99.5
	MET	5.67	5.2	98.9
	NAP	5.61	0.2	96.8
	NAP	0.61	15.4	96.7
	CAR	5.67	8.6	99.8
	CAR	0.67	13.3	99.8
Series 2 [3.2 MLSS]	MET	3.25	22.6	100
	MET	3.25	20.3	100
	NAP	3.16	28.7	99.7
	NAP	0.34	46.6	97.0
	CAR	3.19	11.9	100
	CAR	0.38	17.6	100

Technologies for removal of pharmaceutical compounds

Analytical analyses conducted at the Himmerfjärden WWTP identified 71 pharmaceutical compounds belonging to different therapeutic classes. Organic micropollutants at detected low concentration range of µg - ng l^{-1} did not affect the treatment processes at WWTP. Results from analytical studies indicated continuous discharge of micropollutants to the surface water with a calculated loading amounting to 1.51 kg day^{-1}. Metoprolol, carbamazepine and naproxen were chosen for testing different removal methods (Dlugolecka et al., 2007, 2006, 2005).

The membrane bioreactor (MBR) ZeeWeed10™ placed after the final treatment at the Himmerfjärden WWTP (Sweden) appeared to be an insufficient technology for removal of residual amounts of organic micropollutants from WWTP effluents. Therefore, the application of membrane bioreactor system followed by granular activated carbon filtration was proposed as the efficient technology for removal of pharmaceutically active compounds. This approach could combine biological degradation of easy degradable compounds by activated sludge process performed in MBR and elimination of 'difficult' compounds (diclofenac, carbamazepine, metoprolol) on activated carbon. Additionally, fine membrane filtration can assure the effluent quality that no suspended solids affect the GAC filtration efficiency. In the presented studies (see Table 2), removal rates for all studied compounds exceeded 96%. For carbamazepine, which is known as extremely persistent in aquatic environment and resistant on conventional treatment technologies, the elimination values amounted to 99.8 - 100%.

Behaviour of metoprolol during batch tests and after GAC filtration is presented in figure 5. Analyses of samples indicates the reduction of metoprolol concentration in both performed tests and no metoprolol was detected in samples collected from column with GAC.

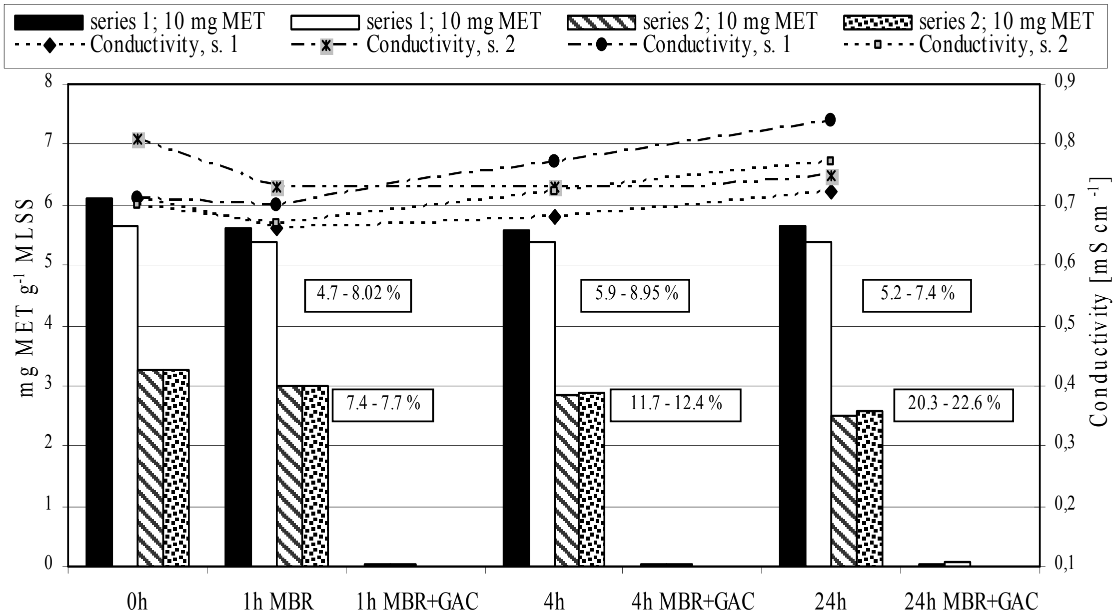


Figure 5. . Results from batch tests and GAC column filtration during tests series spiked with metroprolol (removal ficiency (%) calculated in accordance to initial concentration at 0h) (Dlugolecka et al., 2007)

FUTURE RESEARCH ON WASTEWATER HANDLING IN SWEDEN

Sjöstad research facility – resource for future development in water and wastewater treatment area

The Hammarby Sjöstad plant in Stockholm was built with the aim to study new technologies for compact and sustainable sewage treatment. A pilot wastewater treatment plant is equipped with six treatment lines (including sludge treatment) with possibilities for studies of different technologies (nitrification/denitrification, membrane, reverse osmosis, fluidised bed, Upflow Anaerobic Sludge Bed Reactor, Vibratory Shear Enhanced Processing) and configurations;

- L1 Aerobic treatment, 150 p.e. - Activated Sludge with D/N +- Bio-P +-RO
- L2 Aerobic treatment, 150 p.e. - MBR - Membrane Bio Reactor +- RO
- L3 Anaerobic treatment, 150 p.e. - Fluidised bed + RO
- L4 Anaerobic treatment, 150 p.e. - UASB + RO / precipitation
- L5 Sludge lines, 2 x 150 p.e. - thickening, digestion & dewatering
- L6 Anaerobic treatment, 15 p.e. – VSEP +RO

It is planned that based on Sjöstad plant the national wastewater technology research center will be established with the following goals:

I. Development and optimization of new methods and process configurations for resource effective wastewater treatment
II. Tests for development of equipment for wastewater treatment and separation technology
II. Development of new methods process configurations for drinking water production from wastewater.

Main research areas

Eight research areas have been specified for future studies:

1. Requirements for influent wastewater quality
2. Improvement of existing aerobic and aerobic processes
3. Polishing methods for effluent wastewater
4. Development and evaluation of monitoring and control system for wastewater treatment plant
5. Technologies for side-stream treatment
6. Reduction of wastewater treatment contribution for global warming
7. Methods for increased biogas production
8. Development of new innovative technologies and processes to meet more stringent effluent standards.

REFERENCES

Cema, G., Szatkowska, B., Płaza, E., Trela, J. and Surmacz-Górska, J.(2006). Nitrogen removal rates at a technical-scale pilot plant with the one-stage partial nitritation/Anammox process. *Wat. Sci. Tech.* 54(8), 209-217.

Cema G., Płaza E., Surmacz-Górska J., Trela J and Miksch K. (2005). Study on evaluation of kinetic parameters for Anammox process. In: *Proceedings of the IWA Specialized Conference "Nutrient Management in Wastewater Treatment, Processes and Recycle Streams"*, 19-21 September 2005, Kraków, Poland.

Dlugolecka M. (2007). Pharmaceutical compounds; A new challenge for wastewater treatment plants. Land and Water Resources Engineering, KTH, Stockholm, Licentiatavhandling, TRITA-LWR. LIC Thesis 2037.

Dlugolecka M., Plaza, E. and Dahlberg, A.G., (2007). Two years of experience with semi-technical scale membrane bioreactor (MBR). *Vatten* 63 (1), 69-78.

Dlugolecka M., Płaza E., Trela, J., Dahlberg, A.G., Hultman, B. (2006). Application of Oxygen Uptake Rate (OUR) tests for study of Metoprolol inhibitory effects on activated sludge. *5th IWA World Water Congress & Exhibition Proceedings*, Beijing, China.

Dlugolecka M., Dahlberg, A.G., Plaza, E. (2006). 'Low concentrations of high priority' - Pharmaceutical and Personal Care Products (PPCPs); occurrence and removal at wastewater treatment plants. *Vatten* 62, 139-148.

Gut, L., Plaza, E. Hultman, B. (2007). Assessment of a two-step partial nitritation/Anammox system with implementation of multivariate data analysis, *Chemometrics and intelligent laboratory systems,* 86, 26-34.

Gut L. (2006). Assessment of a partial nitration/Anammox system for nitrogen removal, Licentiatavhandling TRITA-LWR LIC 2031.

Hultman, B., Plaza, E., Stypka, T. (2007). Integrated Water and Sanitation Management in Urban Areas. In: *Baltic University Urban Forum, Urban Management Guidebook I "Urban Water Management"*, Editor E. Plaza, The Baltic University Press, chapter 8, pp. 42-46.

Szatkowska B. (2007). Performance and control of biofilm systems with partial nitritation and Anammox for supernatant treatment. Land and Water Resources Engineering, KTH, Stockholm, Doktorsavhandling, TRITA-LWR PhD Thesis 1035.

Szatkowska, B. Płaza, E., Trela, J., Hultman, B. and Bosander, J. (2007). Combined partial nitritation and Anammox biofilm system as a sustainable solution for supernatant treatment. *Water Practice and Technology*, 2(1) doi10.2166/wpt.2007.0005.

Szatkowska, B., Cema, G., Plaza, E., Trela, J. & Hultman, B. (2007). One-stage system with partial nitritation and Anammox processes in moving-bed reactor. *Water Science and Technology*, 55, (8-9), 19-26.

Szatkowska B., Cema G., Płaza, E., Trela J. and Hultman B. (2006). One-stage system with partial nitritation and Anammox processes in moving-bed biofilm reactor. In: *Proceedings of the IWA Specialized Conference "Biofilm Systems VI"*, 24 – 27 September 2006, Amsterdam, The Nederland.

Szatkowska, B. Płaza, E., Trela, J., Hultman, B. and Bosander, J. (2006). Combined partial nitritation and Anammox biofilm system as a sustainable solution for supernatant treatment. In: *Proceedings of the IWA Specialized conference "Sustainable sludge management: state of the art, challenges and perspectives"*, Moscow, 29-31 May 2006, pp. 531-538.

Szatkowska, B., Płaza, E., Trela, J., Bosander, J. and Hultman, B. (2005) Application of conductivity measurements for monitoring of nitrogen removal in the partial nitritation/Anammox process. In: *Proceedings of the IWA Specialized Conference "Nutrient Management in Wastewater Treatment, Processes and Recycle Streams*", 19-21 September 2005, Krakow, Poland.