Back to basics: high-loaded activated sludge

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INTRODUCTION

Over the past 100 years, the main goal of the activated sludge process has been to remove pollutants from wastewater. The focus was originally on organic substances but through process refinement has later expanded to include removal of phosphorous and nitrogen. Although pollutant removal will remain the most important goal of wastewater treatment plants (WWTPs), we expect that in the future the activated sludge process can also play a major role in resource recovery from wastewater.

In modern treatment plants, removal of organics and nitrogen is often combined in a nitrifying activated sludge process, which then has to be low loaded. However in process configurations where nitrogen removal is not needed or nitrification takes place in a separate system, for instance a post nitrifying biofilm system, high loaded activated sludge systems can be a good, compact and energy efficient alternative. Additionally, in recent years anaerobic oxidation of ammonium (anammox) has evolved as a feasible process technology for treatment of nitrogen-rich sludge liquor streams. Anammox processes are energy-efficient as they reduce the oxygen-requirements and do not consume organic carbon. Currently, pilot trials are under way for the development of mainstream anammox-based processes with one such pilot-trial being carried out at the Sjölunda WWTP in Malmö, Sweden. Assuming main-stream anammox is implemented, the activated sludge process could go back to organics removal only. Rather than oxidising the organics, a high-loaded activated sludge process should be designed for maximum recovery of the organic material through adsorption and non-oxidative uptake. The recovered organics could be used for methane production through anaerobic digestion or valorised in other ways (e.g. production of polyhydroxyalkanoates).

The goal of this poster is to present a vision for the role of high-loaded activated sludge as a resource recovery process at the Sjölunda WWTP of the future. We calculate potential impacts on the plant and identify research needs for the implementation of such a process.

SJÖLUNDA WWTP – NOW AND IN THE FUTURE

At the Sjölunda WWTP (Figure 1) in Malmö, Sweden, pre-precipitation in primary settlers and a high-loaded activated sludge plant for COD removal (aerobic solid retention time (SRT) of 1-2 d) precedes the nitrogen removal generating a wastewater with a BOD_7:NH_4^+-N ratio of around 0.5 g/g. Nitrification is performed in trickling filters with plastic media followed by two-stage moving-bed biofilm reactors (MBBRs) for denitrification with methanol as the carbon source. The existing MBBRs are thought to be reused as a part of the future mainstream nitritation-anammox plant. The existing activated sludge tanks are thought to be optimized for removal of organics through adsorption and non-oxidative uptake.

RESOURCE CONSUMPTION AND POTENTIAL SAVINGS

Currently, the Sjölunda WWTP consumes over 2000 tons of methanol-COD per year for post-denitrification. With anammox-based nitrogen removal, this would no longer be required. The pre-settled COD load entering the activated sludge basins is about 40 000 kg/d. The fate of this organic load can be simulated using an activated sludge model such as ASM1 (Gujer and Henze, 1991). Such a simulation suggests that at lower solids retention time (i.e. higher organic loading), the oxygen consumption per removed unit of COD will be lower, the biomass production will be higher, and the biomass will consist of a larger fraction of adsorbed organic material (Figure 2). Martinello (2013) evaluated the activated sludge process at the Sjölunda WWTP using ASM1 and suggested that lowering the SRT from 32h to 20h could reduce aeration energy requirements by 23%, increase biogas production by 10%, while the effluent COD concentration would increase by 7%. Currently, the electric power consumption at Sjölunda is about 50 MWh/d and the activated sludge process accounts for about 30% of this.

RESEARCH NEEDS

Reducing energy requirements and increasing resource recovery in an activated sludge process by increasing the organic loading is not as straight-forward as indicated above. Model assumptions valid at longer SRTs may not hold at low SRTs. Indeed, the ASM models are not designed to deal with high loads and small SRTs (<1 d) (Henze et al. 2000). Therefore, to predict the behavior of high-loaded activated sludge systems, further knowledge is needed in several areas.

At low SRTs we can expect the microbial composition of the activated sludge to change as slow-growing microorganisms are washed out. This could have several consequences for our ability to simulate process performance:

- The biodegradability of the incoming organic material would be affected where organic substances that were previously degraded by slow-growing microbes may at low SRT be considered inert (Haider et al. 2003; Henze et al. 2002).
- The composition of predators in the sludge may change and affect the apparent decay rate.
- Kinetic coefficients such as maximum growth rate, yield, half-saturation constant, and decay rate, determined at longer SRT are not necessarily valid for short SRT sludge.
- The flocculation and settling ability of sludge may change and affect solids separation. Problems with foaming could appear (this has been observed at the Sjölunda WWTP).

We need further knowledge about the relationships between microbial community composition, kinetic coefficients, degradability of incoming organics, and settling and foaming problems in high-loaded activated sludge. Knowledge of the mechanisms of biodegradation and the influence on the solids separation is important as a deteriorated removal of organic matter may not be acceptable in relation to the effluent standards of the WWTP.

Particulate and colloidal compounds account for the major fraction of the biodegradable organics in municipal wastewater. The activated sludge models assume these substances are instantaneously entrapped in the activated sludge biomass (Henze et al. 2000), and at short SRT adsorption could become the major mechanism of organics removal in the sludge. However, adsorption may be affected by different characteristics of both the sludge and the particles themselves. The mechanisms of adsorption of organic compounds by high-loaded sludge at short contact times need further research.

Other aspects to consider regarding the design of a high-loaded activated sludge plant include whether the system could be designed to enrich for sludge with enhanced internal storage (i.e. to enhance non-oxidative uptake of easily biodegradable organics), whether biological phosphorous removal should be included, whether a portion of the organic load should be used for denitrification of the nitrate generated by the anammox process, the required quality of the wastewater fed to the nitritation-anammox process, and last but not least, how to best valorise the increased amount of sludge produced.

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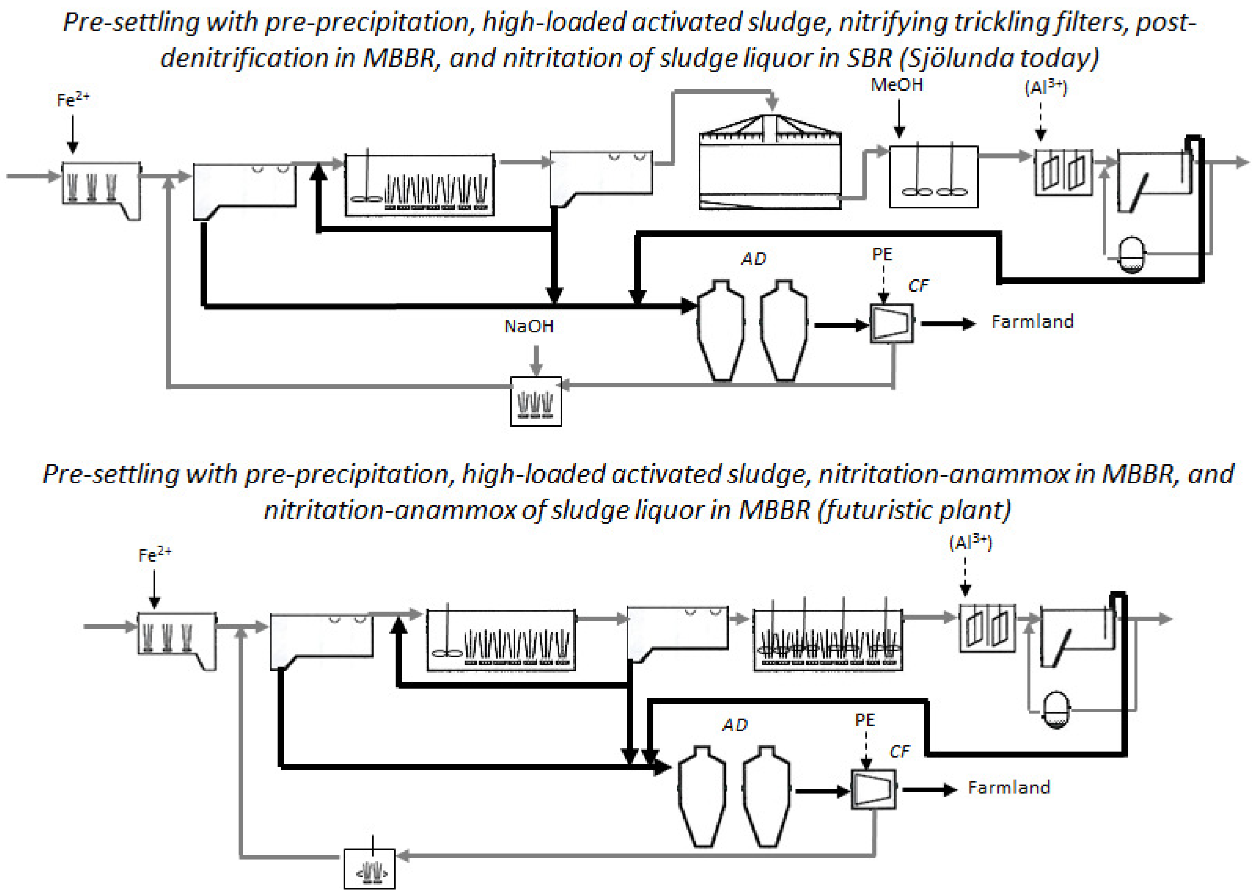

Figure 1 Today's plant layout and a futuristic plant layout.

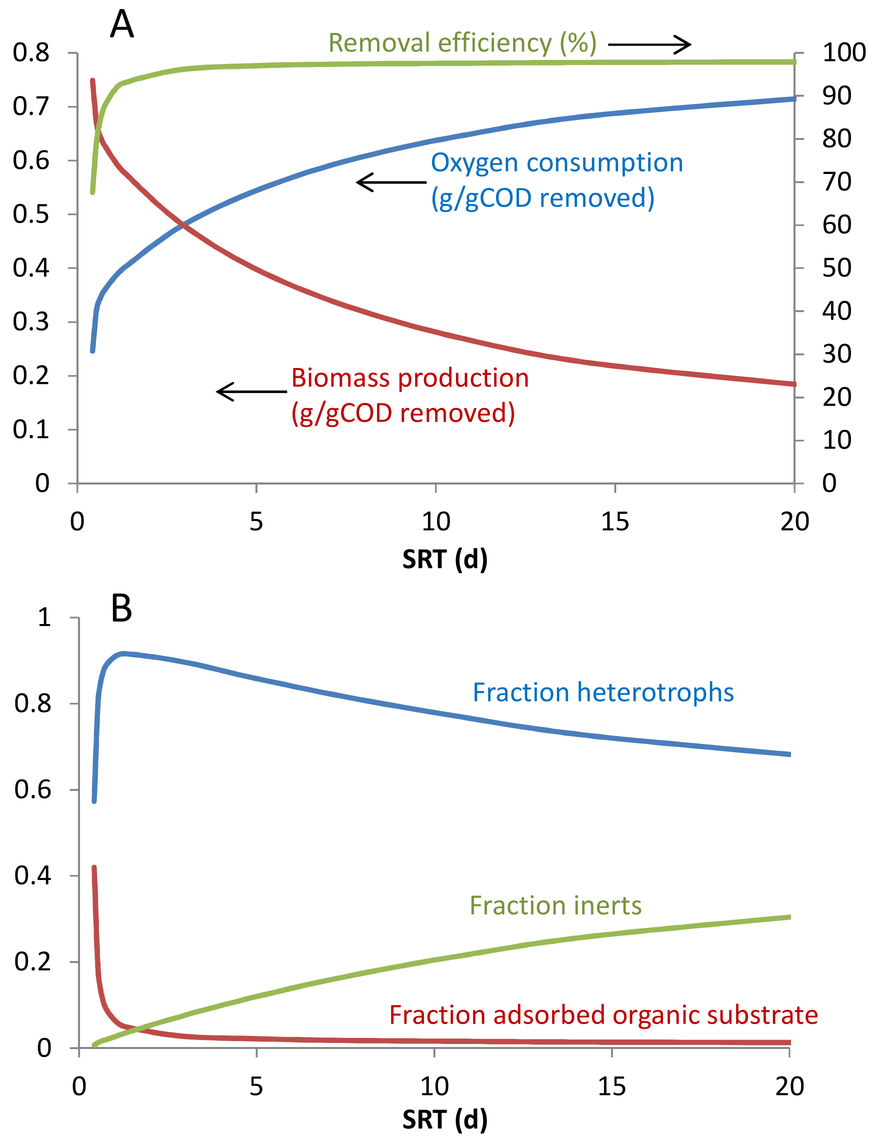

Figure 2 (A) Simulated oxygen consumption, biomass production, and COD removal rate at various solids retention times. (B) Simulated fraction heterotrophs, adsorbed organics, and inert material in the mixed liquor suspended solids. A simplified version of ASM1 (Model C in Gujer and Henze, 1991) was used for the simulation.

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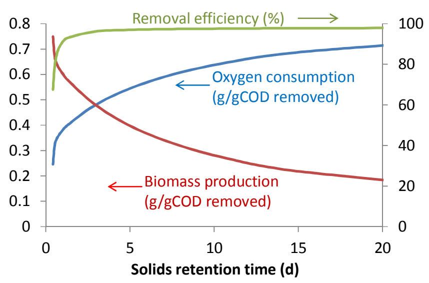
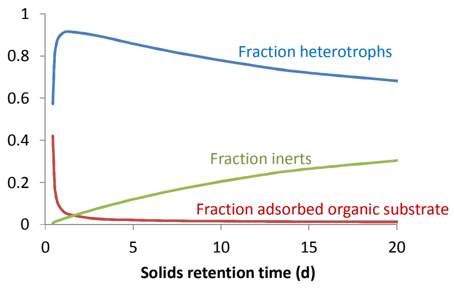
INTRODUCTION

In modern wastewater treatment plants, organics removal and nitrification is often combined in the activated sludge process, which then has to be operated with a long solids retention time and be low-loaded.

With the development of new nitrogen removal processes and an increased focus on resource recovery, high-loaded activated sludge processes should be designed to maximize recovery of organic material through adsorption and non-oxidative uptake, and to minimize oxygen consumption per unit of removed organics.





Left: Simulated oxygen consumption, biomass production, and COD removal rate at various solids retention times. Right: Simulated fraction heterotrophs, adsorbed organics, and inert material in the mixed liquor suspended solids. A simplified version of ASM1 (Model C in Gujer and Henze, 1991) was used for the simulation.

Our view of the evolution of the aerobic activated sludge process

Past
-*High-loaded activated sludge*
-Focus on organics removal

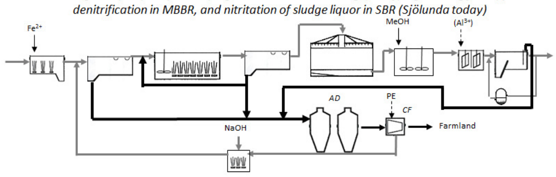
Present
-*Low-loaded activated sludge*
-Focus on combined removal of organics and nutrients, minimization of sludge production

Future
-*High-loaded activated sludge*
-Focus on maximized resource recovery and minimized resource use
-Organics mainly removed through non-oxidative uptake and valorized in anaerobic processes
-Nutrients removed/recovered in separate processes such as anammox, stripping and capture, and struvite precipitation

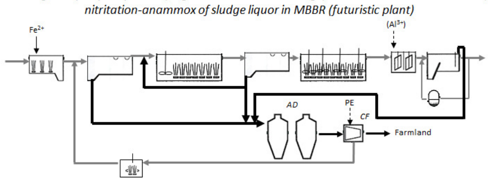
A VISION FOR SJÖLUNDA WWTP

Sjölunda WWTP in Malmö, Sweden, consists of primary settlers, a high-loaded activated sludge process, nitrifying trickling filters and post-denitrification with methanol in MBBRs. In a future vision for the plant, the MBBRs would be used for mainstream nitritation-anammox and the high-loaded activated sludge would be optimized for removal of organics through adsorption and non-oxidative uptake. Potential savings include 2000 ton methanol-COD/year. Lowering the activated sludge SRT from 32 to 20h could result in 23% lower aeration requirements, and 10% higher biogas production (Martinello, 2013).

Pre-settling with pre-precipitation, high-loaded activated sludge, nitrifying trickling filters, post-denitrification in MBBR, and nitritation of sludge liquor in SBR (Sjölunda today)

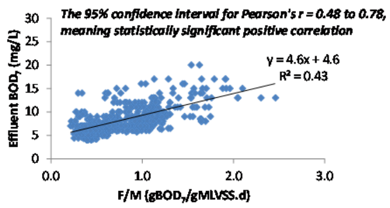


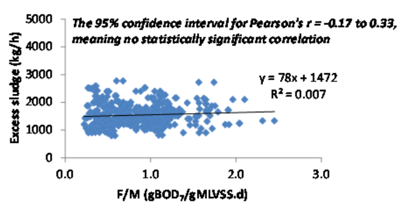
Pre-settling with pre-precipitation, high-loaded activated sludge, nitritation-anammox in MBBR, and nitritation-anammox of sludge liquor in MBBR (futuristic plant)



EXPERIENCES FROM GRYAAB

The Rya WWTP in Gothenburg, Sweden consists of primary settlers, denitrifying activated sludge, nitrifying trickling filters, and post-denitrification in MBBRs. Analysis of over 4 years of data from the full-scale plant showed a statistically significant positive correlation between organic loading (temperature-corrected F/M ratio*) and effluent BOD_7 concentration. No significant correlation between loading and amount of withdrawn excess secondary sludge could be observed.





*The temperature-corrected F/M ratio was calculated to account for variations in biological reaction rates with temperature (T): $(F/M)_{20°C} = (F/M)_T/\theta^{(T-20)}$, where θ was assumed to equal 1.135 (Metcalf & Eddy et al., 2003).

RESEARCH NEEDS

Reducing energy requirements and increasing resource recovery in an activated sludge process by increasing the organic loading may not be straight-forward. Here are a few things to consider:

- The effluent quality could deteriorate because of higher selective pressure on the microbial community at lower SRT, resulting in lower biodegradability of the incoming organics. What is the trade-off between lower treatment efficiency and higher resource efficiency?
- The flocculation and settling ability of sludge may change and affect solids separation. Problems with foaming could appear, which has been observed at the Sjölunda WWTP. How can this be prevented?
- What mechanisms govern adsorptive- and non-oxidative uptake of organics by the activated sludge, and how can we design processes to maximize this uptake?
- How do the high-loaded activated sludge integrate with other processes at the plant, e.g. is a portion of the organics needed for denitrification and what are the treatment requirements if the effluent is fed to a main-stream anammox process?
- How should we valorize the increased amount of organic material recovered in a high-loaded activated sludge plant?

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