System stability and regime shifts

An experimental sequencing batch reactor for nitrogen removal from urine by partial nitritation and anammox was monitored for over a year. Over the course of the experiment the reactor experienced considerable dynamics in performance as well as changes in the microbial community. We hypothesize that these dynamics can be interpreted as ecological regime shifts. Regime shifts are defined as rapid reorganizations of ecosystems from one relatively stable state to another. While the concept is widely applied in ecology, it has not really been considered for microbial ecology. A better understanding of the causes and dynamics of regime shifts in microbial ecosystems is an important foundation to enable the stable operation of biological reactors.

Objectives

In this project we studied a sequencing batch reactor for nitrogen elimination from source separated urine combined nitrogen elimination and anammox (PNAA process, Fig. 1). Due to the high organic load of urine, heterotrophic denitrifying organisms also play an important role.

- What drives microbial community composition?
- Can performance be linked to microbial community structure?
- Are communities stable during stable operation?
- How to improve performance and stability?

Dynamics of population structure

The bacterial population showed gradual population changes during the initial monitoring period (also relative to 2007 samples). A strong shift occurred after the reactor reached peak performance. After this shift, the population entered a prolonged period of stability (Fig. 2, 3). We distinguished three phases in the microbial community development (green, red, purple indicators, Fig. 2 and throughout).

Methods

Chemical and physical parameters were measured continuously by probes or from samples, performed every 2-3 days, and analysis using standard methods. The microbial community in the reactor was sampled approximately monthly to monitor the long-term development. Microbial populations were studied based on DNA extracted from sludge samples. Community structure was characterized by automated ribosomal intergenic spacer (ARISA) analysis.

Genetic markers (functional genes, 16S rRNA genes for anammox bacteria) for major processes of the nitrogen cycle were studied using quantitative real-time PCR.

Figure 3: pPCR quantification of the abundance of key functional groups of nitrogen cycle processes in the reactor.

Main Results

- Bacterial population structure (not diversity) changed in parallel to process performance trends
- pH setpoint, aeration (Qair), Tanox, and NH4+ inflow were identified as major drivers of community composition (Fig. 3)
- The dynamics in the reactor can be described as regime shifts – rapid changes of the ecosystem followed by phases of relative stability
- First regime shift caused by reduction of pH setpoint and changes in aeration that resulted in shorter cycles and less favorable conditions for anammox bacteria
- pPCR indicates that a breakdown of the anammox bacteria population was a main factor in the performance decrease of the reactor

Conclusions

Biological reactors act as complex ecological systems. Small changes in external parameters can trigger regime shifts that affect performance. These new states may be stable, affecting the ability to return the system to a more favorable state. Research into the ecological dynamics of wastewater treatment and other engineered systems is important to understand and predict system behavior.