Improvement of effluent total nitrogen concentration by control of nitrate recirculation flow

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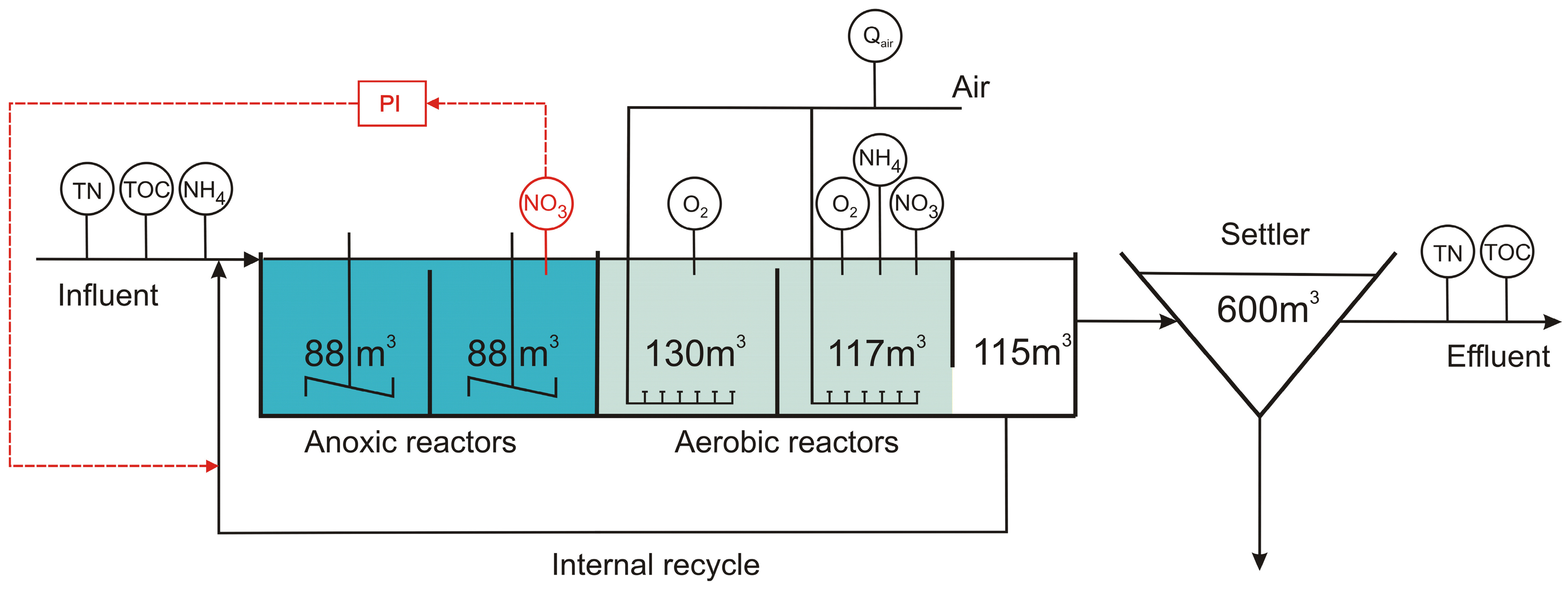
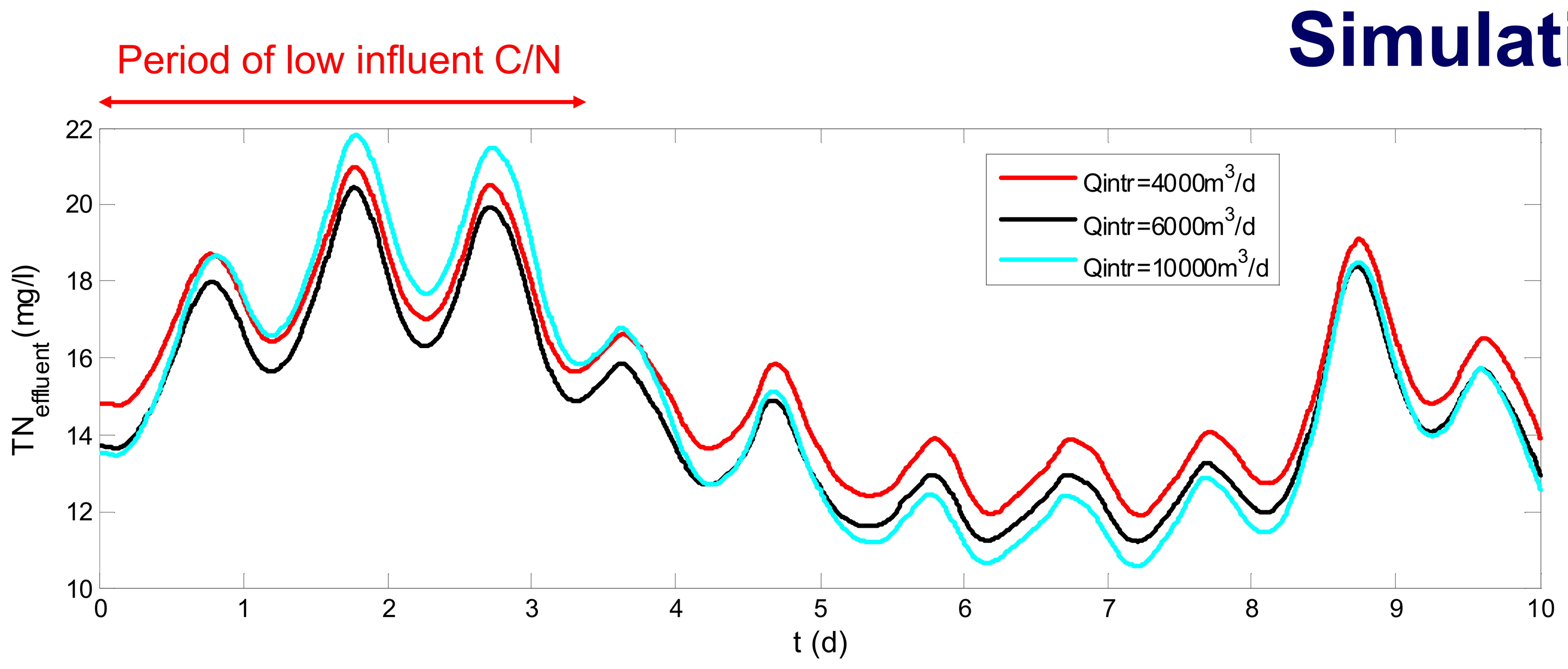
Introduction

This paper addresses the design of PI (proportional-integral) controller that adjusts the nitrate recirculation flow-rate in a predenitrification activated sludge system. The aim is to maximise denitrification capacity of anoxic reactors and so achieve low effluent total nitrogen (TN) concentration. The controller is based on nitrate (NO_3-N) measurement in the last anoxic reactor.
The controller was tested on pilot plant.



Tested case study: MBBR (moving bed biofilm reactor) pilot plant in Domžale-Kamnik wastewater treatment plant.

Simulation results



Simulations with different constant nitrate recirculation flows (Q_{intr}) were performed using a pilot plant simulation model and dynamic real plant influent data.

Simulation results indicate that keeping recirculation flow constant is not an optimal solution. The recirculation flow should be changing dynamically to achieve optimal plant performance at different plant operating conditions.

Simulation results with different internal recirculation flows.

Results from real plant experiments

Nitrate (NO_3-N) PI controller

The nitrate controller was designed as a discrete PI controller with anti-windup protection. The algorithm sampling time was 20s.

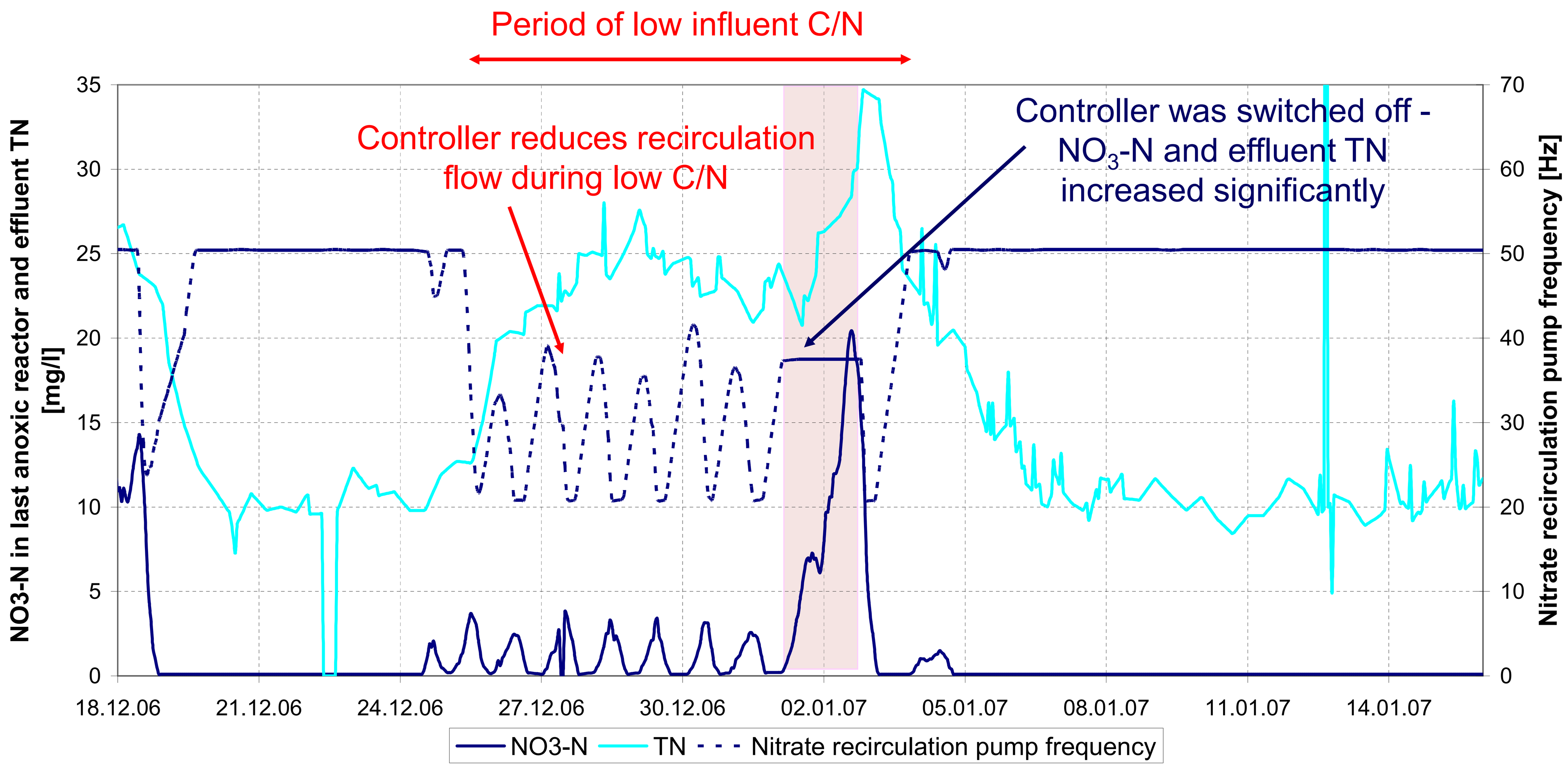
$$u(k)=K_p\left(e(k)+\frac{T_s}{T_i}\sum_{j=1}^{k}e(j)\right)-\frac{T_s}{T_i}\sum_{j=1}^{k-1}\left(u(j)-u_{lim}(j)\right)$$

$$u_{\lim}(k)=\begin{cases}u_{\min}, & \text{if } u(k)<u_{\min}\\ u(k), & \text{if } u_{\min}\le u(k)\le u_{\max}\\ u_{\max}, & \text{if } u(k)>u_{\max}\end{cases}$$

Controller was implemented in Matlab at Jožef Stefan Institute and connected to the pilot plant control system through VPN (Virtual Private Network) connection.

Pilot plant testing results

During normal operating conditions (dry weather) the controller increases the recirculation flow (pump frequency) to the maximum value, which reduces the effluent total nitrogen concentration (TN) to 10mg/l.
During the holidays (from 24.12.2006 to 5.1.2007) the denitrification capacity of anoxic reactors was reduced because of low influent C/N ratio. The controller reduced the recirculation flow so that the desired NO_3-N of 1mg/l in the last anoxic reactor was achieved. When the controller was switched off for some time on 2.1.2007, the NO_3-N in the last anoxic reactor and effluent TN increased significantly.



Manipulation of recirculation pump frequency by PI controller during experimentation, and NO3-N and TN concentrations.

Quality and energy issues

With denitrification control the average effluent TN during dry weather conditions was reduced for around 3mg/l. During abnormal conditions (rain, holidays) it prevented from very high effluent TN peaks. Reduction of aeration energy consumption was also observed as influent organic carbon was consumed to a greater extent in anoxic reactors and did not pass over to aerobic reactors where oxygen is needed for its conversion.

Internal recycle flow operating regime	Internal recycle Flow	Airflow [m^3/h]	Effluent TN [mg/l]
Manually adjusted (constant)	2.3Q_{in}	1727	13,06
PI nitrate controller	4Q_{in}	1307	10,30

Comparison of pilot plant operation at two different recycle flow operating regimes.

Conclusions

Keeping internal recirculation constant is sub-optimal in all operating conditions. By controlling nitrate concentration in the last anoxic reactor at a low value and adjusting the recirculation flow, the denitrification capacity of anoxic reactors is optimised. Important quality improvements (reduced effluent TN) and energy savings (reduced aeration energy consumption) were observed when testing the controller on the pilot plant.