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IMPACT OF LOW-RATE SUBSTRATE REMOVAL ON THE PERFORMANCE OF DENITRIFYING SYSTEMS[1]

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Abstract

Strict effluent *N* criteria may also require the use of slowly biodegradable substrate as carbon source for denitrification. The paper draws attention to the fact that oxygen penetration through the surface of uncovered denitrification basins may significantly deteriorate the efficiency when substrate removal rate is low, whereas at high consumption rates this impact may prove to be negligible.

Results of comparative lab-scale experiments carried out in both batch and continuous-flow operation revealed that the reason why denitrification rates are much more severely affected at low substrate consumption rates is the increased dissolved oxygen concentration that occurs due to the decreased ability of its removal. In the comparative batch experiments a zero-head-space reactor and a reactor with an open surface were applied using different samples of preclarified wastewater deriving from an existing treatment plant. In the continuous-flow experiment two differently arranged activated sludge systems were operated simultaneously, fed by a model wastewater containing peptone as carbon source. The total reactor volume serving predenitrification was identical in both arrangements; however, in one of the systems it was compartmentalized into three reactors. None of the reactors were covered in this experiment.

The dissolved oxygen concentration raised significantly in both of the batch and continuous-flow experiments when the readily biodegradable substrate had been depleted. The results supported that in cases when readily denitrifiable carbon source is not in a pronounced excess, staging of anoxic reactors may significantly improve the efficiency of denitrification through maintaining relatively high substrate removal rate and thereby low oxygen concentration in the first basins.

Keywords: activated sludge, denitrification, oxygen penetration, bioreactor staging.

1. Introduction

Although metabolic advantage of oxygen consumption over denitrification is well-known [1], denitrifying systems are commonly built as open-air reactors because the impact of oxygen penetration on the system performance is assumed to be negligible. This assumption is certainly valid in conditions when the readily denitrifiable

[1]This paper is based on the poster presentation (Impact of low-rate substrate removal on the performance of denitrifying systems) given at the *ENVIRO 2002/IWA World Water Congress*, Melbourne, Australia, April 7–12, (2002).

carbon source of the wastewater is in excess to the amount of oxidized nitrogen forms to be removed in the treatment process. Due to different water consumption habits, differently established sewer systems and different climatic conditions, however, the ratio of readily denitrifiable substrate concentration to the influent nitrogen concentration may significantly differ from one wastewater to the other. In addition to the eventually occurring substrate shortage, increasingly strict effluent nitrogen criteria increase the necessity of using low-rate substrate removal processes for denitrification. The purpose of this paper is to draw attention to the fact that oxygen penetration through the surface of uncovered denitrification basins may significantly deteriorate the efficiency when substrate removal rate is low, whereas at high consumption rates this impact may prove to be negligible.

2. Comparative Batch Experiments

The batch experiments were carried out in the arrangement shown in *Fig. 1*. The zero-head-space reactor [2] assured completely anoxic conditions whereas the reference system allowed oxygen penetration through the open reactor surface. In the batch experiments, carried out at 20 °C, preclarified wastewater and activated sludge samples of a domestic treatment plant were used and KNO_3 was applied for the adjustment of the initial nitrate concentration.

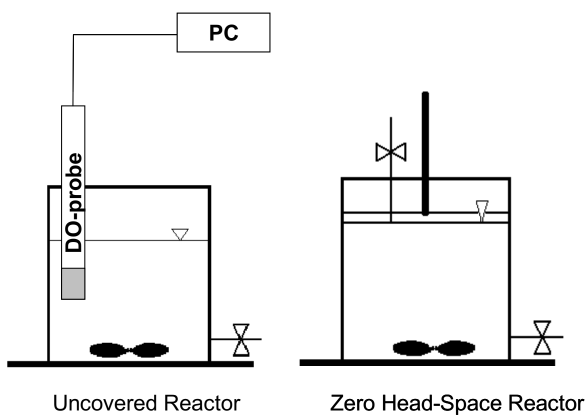

Fig. 1. Batch experimental setup with the uncovered and the zero-head-space reactors

Data of two different experiments, one with substrate in excess and the other one with substrate shortage, are shown in *Figs. 2–4*. It is obvious that in substrate excess oxygen penetration through the open reactor surface does not have a significant impact on the denitrification rate. The reasons are twofold [5, 3, 4]. There is enough substrate available for both oxygen and nitrate consumption and the high consumption rate keeps the dissolved oxygen concentration at a low level. Low substrate consumption rate, however, allows the dissolved oxygen concentration to rise up to relatively high values, which represents an additional, kinetic inhibition factor for denitrification.

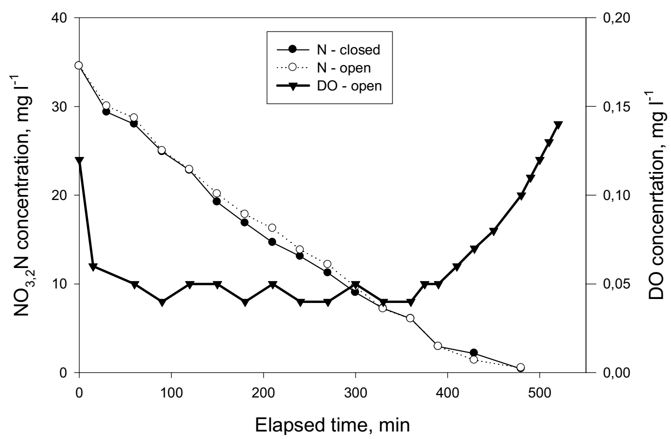

Fig. 2. Results of the batch experiment with substrate in excess ($MLVSS_{INI,\ closed}$ = 600 mgl^{-1} COD, $MLVSS_{INI,\ open}$ = 660 mgl^{-1} COD).

3. Comparative Continuous-Flow Experiments

Since the batch experiments referred to the advantage of a high-rate substrate removal in the performance of the denitrifying reactors, the continuous-flow experiments were carried out using staged and unstaged denitrification basins in two experimental systems operated simultaneously. The arrangement of the reactors is shown in *Fig. 5*. The system with the staged denitrification basins contained 3 anoxic reactors (with volumes of 0.5 l, 0.5 l and 1 l, respectively) connected in series. In the reference system the volume of the denitrification reactor was equal to the total volume of the three reactors of the staged system (2 l). None of the reactors were covered. The anoxic reactors were followed by two aerated basins with a total volume of 5 l. The concentration of the biomass was maintained at 2–2.5 gl^{-1} through the sludge wastage.

The systems were fed by a model wastewater containing peptone as carbon source. The influent also contained 60 mgl^{-1} NH_4NO_3, 21 mgl^{-1} NaCl, 10 mgl^{-1} $MgCl_2$. 7 H_2O, 12 mgl^{-1} $CaCl_2$, 28 mgl^{-1} NaH_2PO_4 and was supplemented by KNO_3 to an extent that assured the presence of nitrate throughout the anoxic basins. In order to investigate the impact of substrate availability on the system performance, the carbon source was applied in different ratios compared to the influent nitrogen. Results of the experiment are shown in *Figs. 6–8*.

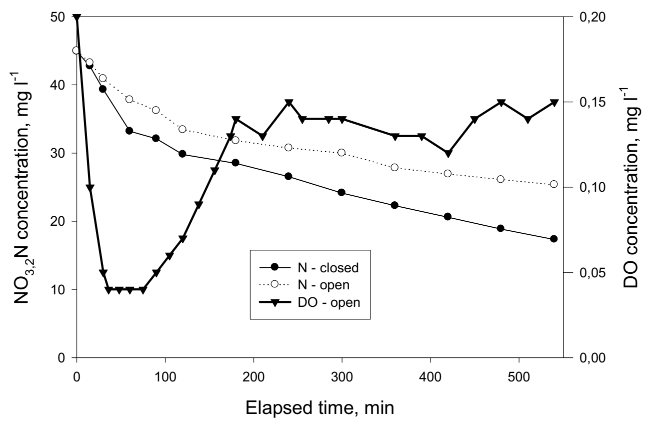

Fig. 3. Results of the batch experiment with substrate shortage ($MLVSS_{INI,\ closed}$ = 1450 mgl^{-1} COD, $MLVSS_{INI,\ open}$ = 1160 mgl^{-1} COD).

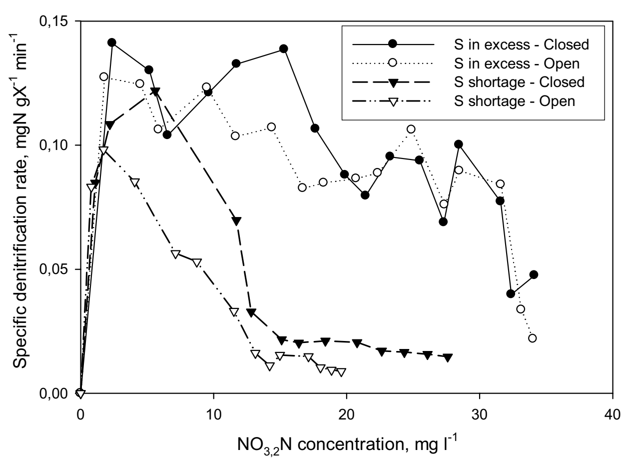

Fig. 4. Measured denitrification rates in the experiments with substrate in excess and substrate shortage

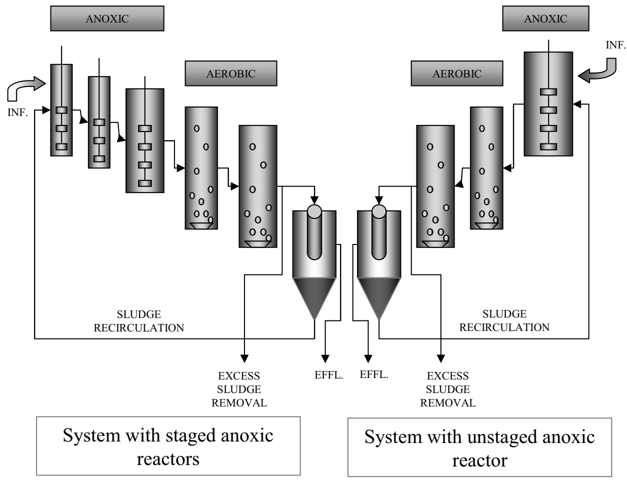

Fig. 5. Layout of the continuous-flow experiment

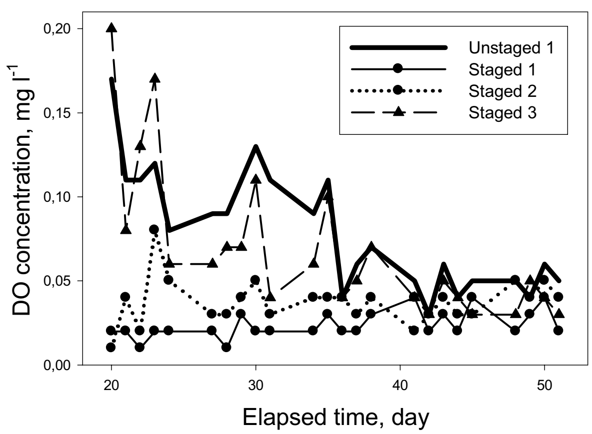

Fig. 6. Dissolved oxygen concentrations measured in the anoxic basins of the experimental systems

Data depicted in *Fig. 6* refer to significant differences regarding the conditions of denitrification in the non-aerated reactors. The dissolved oxygen concentration in the first basin of the staged system proved to be low throughout the whole experiment. In the second anoxic stage similarly low DO values could be detected, however, on the 23rd day of the experiment a sharp decrease of the influent COD level resulted in significantly increased dissolved oxygen concentration even in this basin (see *Figs. 6* and *7*).

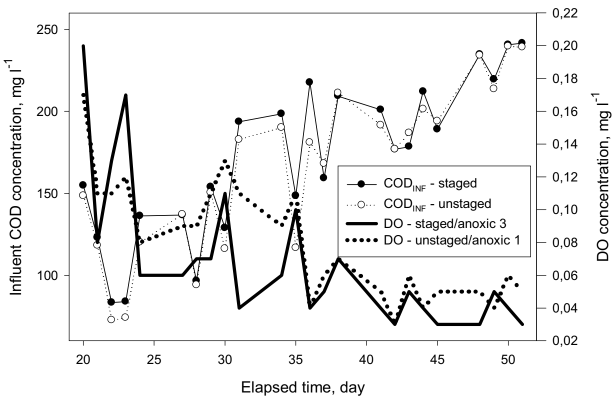

Fig. 7. Impact of the COD concentration in the mixture entering the first reactors of the systems on the DO concentrations in the unstaged anoxic reactor and in the 3 rd anoxic reactor of the staged system.

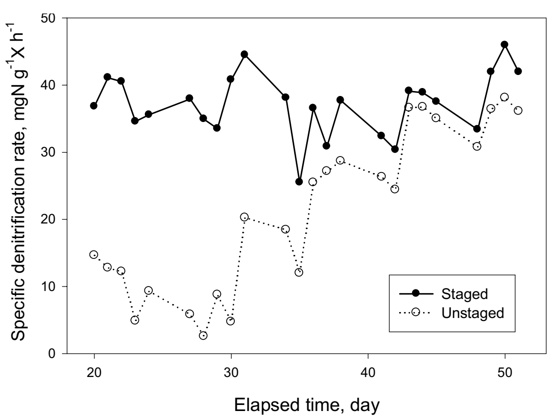

Fig. 8. Specific denitrification rates measured in the differently arranged experimental systems

Both in the third non-aerated unit of the staged system and in the anoxic reactor of the reference system relatively high dissolved oxygen concentration values were measured in the first part of the experiment, when the influent COD concentration was maintained at low levels. In *Fig. 7*, the measured COD concentration of the mixture deriving from the influent and the recycled sludge is shown together with the DO concentrations detected in these reactors. The impact of the substrate availability is obvious. Low DO concentration of the first and second anoxic reactors of the staged system can be attributed to the high substrate consumption rate in these reactors, whereas the high dissolved oxygen concentration level of the third anoxic reactor as well as that of the non-aerated unit of the reference system can be explained by the low-rate substrate consumption.

Values of the specific denitrification rates measured in the differently arranged experimental systems are depicted in *Fig. 8*. Data clearly show that staging of the non-aerated reactor may significantly increase the denitrification efficiency in cases when the influent readily biodegradable substrate is not in a pronounced excess to the amount of the oxidized nitrogen forms to be removed in the treatment process. This advantage becomes smaller with decreasing substrate shortage. Results suggest that appropriate bioreactor configuration of anoxic vessels, i.e. assuring high-rate substrate consumption by staging, and/or covering reactors of low-rate substrate consumption essentially improves the performance when substrate deficiency may occur in the influent.

4. Conclusions

Strict effluent *N* criteria coupled with a relative shortage of readily denitrifiable carbon source may also require the use of slowly biodegradable substrate for denitrification. In order to investigate the role of bioreactor arrangement and thereby the substrate consumption rate established in the anoxic reactors, comparative lab-scale experiments were carried out in both batch and continuous-flow operation. Results revealed that the reason why denitrification efficiency is much more severely affected at low substrate consumption rates is the increased concentration of dissolved oxygen that occurs due to the decreased ability of its removal.

In the batch experiments a zero-head-space reactor and a reactor with an open surface were simultaneously operated by using preclarified wastewater and activated sludge samples of an existing treatment plant. When readily biodegradable substrate proved to be in excess, practically no influence of the oxygen penetration on denitrification rate could be detected. On the other hand, when substrate proved to be in shortage, denitrification slowed down with a significantly higher rate in the system where the surface was not covered.

In the continuous-flow experiment two differently arranged activated sludge systems were operated simultaneously and were fed by a model wastewater containing peptone as carbon source. The total reactor volume serving predenitrification was identical in both systems; however, one of the anoxic basins was compartmentalized into three reactors. None of the reactors were covered in this experiment. The experiment was carried out by applying the carbon source in different ratios to the influent nitrogen. The dissolved oxygen concentration remained at low levels in the first and mainly also in the second non-aerated reactors of the staged system, whereas both in the third reactor of the staged system and in the non-aerated unstaged reactor the DO level proved to be dependent on the influent COD concentration and raised to relatively high values with decreased influent COD levels. The experimental data revealed that at low-rate substrate consumption denitrifying basins may in fact be low DO reactors.

Data supported that staging of the non-aerated reactor may significantly improve the denitrification efficiency through maintaining relatively high substrate removal rate and thereby low oxygen concentration in the first basins when the influent readily biodegradable substrate is not in a pronounced excess to the requirement of the oxidized nitrogen forms to be removed in the treatment process.

5. Nomenclature

Closed	closed anoxic vessel
$\Delta NO_{3,2}N$	consumed nitrate+nitrite nitrogen concentration (mg l^{-1} N)
EFFL	effluent treated wastewater
INI	initial condition
INF	influent wastewater
MLVSS	mixed liquor volatile suspended solids (mg l^{-1} COD)
$NO_{3,2}N$	nitrate + nitrite nitrogen concentration (mg l^{-1} N)
Open	open anoxic vessel
O_2, DO	dissolved oxygen concentration (mg l^{-1} O_2)
S	carbon source
Staged	3-stage anoxic selector
Unstaged	unstaged anoxic selector

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