

Distillery fusel oil as an alternative carbon source for denitrification – from laboratory experiments to a full-scale application

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Introduction

Denitrification can be enhanced (in terms of the rate and efficiency) within the existing capacities of biological nutrient removal (BNR) wastewater treatment plants (WWTPs) by adding external carbon sources to anoxic compartments. Commercially available compounds (e.g. methanol) are effective, but expensive. In recent years, a shortcut in the nitrogen conversion pathway, i.e. nitrification-denitrification via NO₂-N instead of NO₃-N, has been promoted as an alternative solution in order to reduce the oxygen demand for nitrification and organic carbon demand for denitrification. Fux and Siegrist (2004) noted, however, that significant N₂O production can occur at elevated NO₂-N concentrations in the reactor. Therefore, full denitrification (via NO₃-N) would be sustainable and economically feasible if a cheap and effective carbon source could be found. The distillery waste product (fusel oil) has already been identified as a viable carbon source in sidestream treatment systems performing full nitrification-denitrification as the observed nitrate utilization rates (NURs) with the support of fusel oil were comparable with ethanol (Makinia et al., 2011).

This paper presents further results of a 3-year project concerning the use of fusel oil as a carbon source to enhance denitrification at municipal WWTPs. The properties of fusel oil in terms of temperature dependency, acclimation period, and the effects on NO₂-N and PO₄-P behaviour were evaluated under laboratory conditions. First results obtained during a full-scale application were used to identify similarities and differences with the laboratory-scale results.

Materials and Methods

Laboratory experiments. Two types of batch experiments, including the conventional denitrification and denitrification preceded by an anaerobic phase, were carried out with non-acclimated mixed liquor from a large (600,000 PE) BNR WWTP located in the city of Gdansk (northern Poland). The acclimation of biomass to fusel oil was also investigated in a bench-scale Johhnesburg (JHB) system fed with the settled wastewater from the Gdansk WWTP.

Full-scale experiments. A full-scale application of dosing fusel oil was tested at another large (500,000 PE) BNR WWTP located in the city of Gdynia (JHB process configuration). The dosage rate to a selected (test) line was approx. 0.4 m³/d and NO₃-N concentrations were continuously monitored in the test line and reference line (one of the lines without dosing fusel oil). In addition, conventional NUR measurements were carried out on a regular basis (once per week) under laboratory conditions with the biomass withdrawn from both studied lines.

Results and significance of the findings

Three samples of fusel oil from a local distillery, providing its waste product for the experiments, were analysed by gas chromatography (29 compounds). The dominating compound was 2-methyl-1-butanol (37.2-42.3% by weight), whereas ethanol and unknown compounds constituted 3.6-4.3% and 24.8-37.9%, respectively.

In the conventional denitrification tests with the support of fusel oil, the measured NURs ranged from 0.6 to 1.3 g N/(kg VSS·h) at the ΔCOD:ΔN ratio = 5.9 (±0.83) g COD/g N. These results revealed a very strong temperature dependency of the denitrification process ($\theta = 1.15$, $R^2 = 0.92$) in the range of examined process temperatures (13-18 °C). During all the experiments, fusel oil had minor (or no) effects on the behaviour of NO₂-N and PO₄-P as their concentrations did not exceed 0.1 g N/m³ and 0.4 g P/m³, respectively. For comparison, in similar experiments with the settled wastewater, NO₂-N accumulations up to 5 g N/m³ occurred in the first phase of the test and NO₂-N

was subsequently utilized in the second phase. The initial release of $\text{PO}_4\text{-P}$ was observed until the readily biodegradable substrate was present in the solution.

When adding fusel oil at the beginning of the anoxic phase was preceded by an anaerobic phase (biomass mixed with the settled wastewater), the range of observed NURs, i.e. 1.4-3.5 g N/(kg VSS·h), was higher to the reference tests without the addition of fusel oil (1.3-2.5 g N/(kg VSS·h)) in the same range of temperatures as above (13-18 °C). The denitrification process was still strongly dependent on temperature but the correlation was poorer ($\theta = 1.09$, $R^2 = 0.39$). No explicit effect of fusel oil on the $\text{PO}_4\text{-P}$ behaviour in the anoxic phase was observed. The anoxic P uptake rates (PURs) in the experiments with and without the addition of fusel oil appeared to vary in similar ranges, i.e. 2.1-3.9 g P/(kg VSS·h) vs. 2.2-3.6 g P/(kg VSS·h).

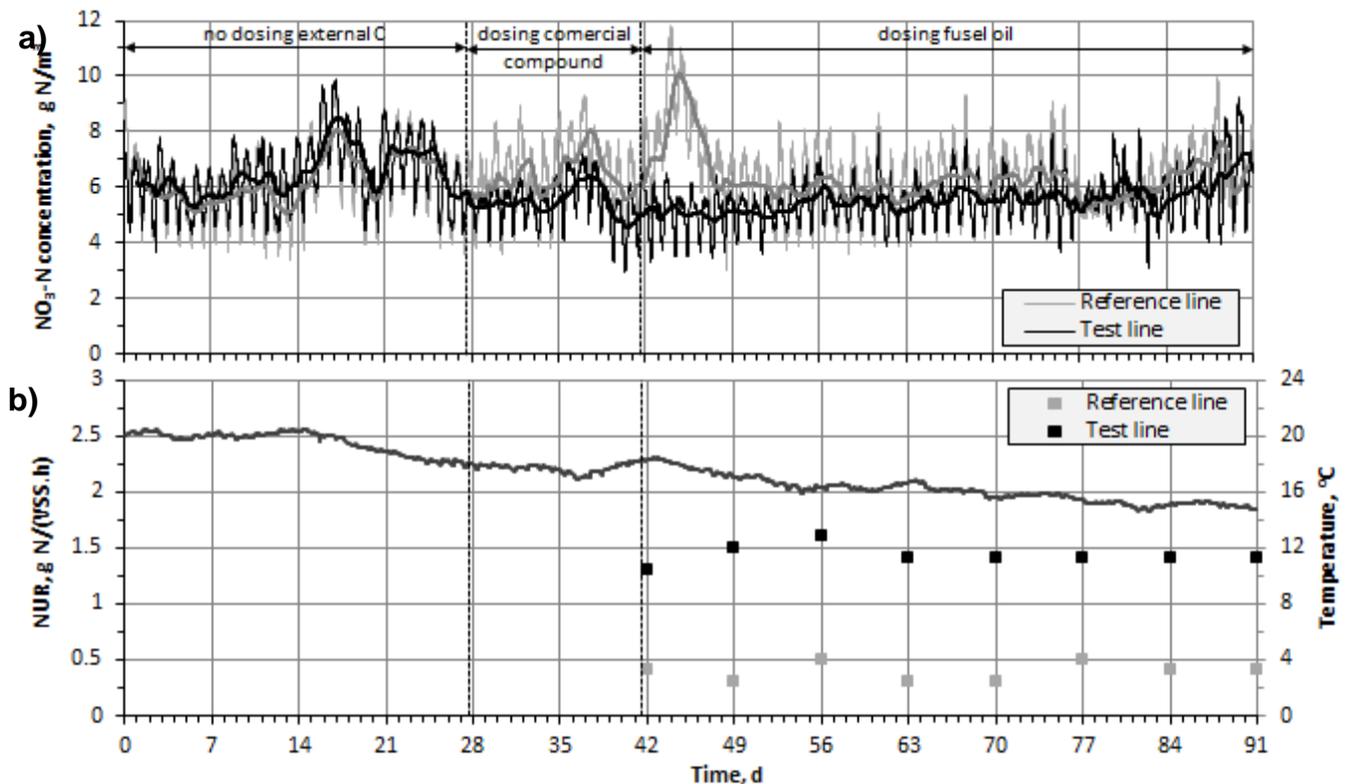


Figure 1. Results of the full-scale experiment at the Gdynia WWTP: (a) behaviour of $\text{NO}_3\text{-N}$ in the test and reference lines (the bold lines represent moving averages with the period of 1 d), (b) process temperature and the NURs determined under laboratory conditions for the mixed liquor from the test line (with dosing fusel oil) and reference line (without dosing fusel oil).

In the full-scale experiments, during the dosage of fusel oil (days 42-91), the average $\text{NO}_3\text{-N}$ concentration in the test line was approx. 1 g N/m^3 lower compared to the reference line (Figure 1a). The measured NURs in the test line (with the addition of fusel oil during the test) were remaining at a constant level of 1.5 g N/(kg VSS·h) and were approx. 3 times higher compared to the rates in the reference line (without the addition of fusel oil during the test) (Figure 1b). These results are consistent with the NURs observed in the bench-scale JHB system. For comparison, a significantly higher increase of NURs was observed during acclimation (under laboratory conditions) of the activated sludge to fusel oil and sludge digester liquor. In that case, the rates were continuously increasing and reached the maximum of approx. 15 g N/(kg VSS·h) after a 3-week acclimation period (Makinia et al., 2011). Such high NURs could not be obtained in the mainstream bioreactor for three major reasons: (1) more complex carbon sources present in the settled wastewater, (2) lower influent nitrogen loads, and (3) mixing of the mixed liquors from all the lines in the return activated sludge (RAS) line (no separation of the acclimated biomass).

References

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