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Performance of a hybrid activated sludge/biofilm process for wastewater treatment in a cold climate region: Influence of operating conditions

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ABSTRACT

The main aim of the study was to investigate a hybrid MBBR process, mostly in terms of organic matter removal and nitrification, when operating with different values of the mixed liquor sludge retention time (SRT), and highlighting the influence of temperature on the process. Based on experience in practice it was hypothesized that nitrification could be maintained at far lower SRT's than in conventional activated sludge systems and with high organic loading rates applied. A field gathering campaign has been carried out on a hybrid activated sludge/biofilm. The obtained results highlighted that the pilot plant was capable to remove the organic matter at loading rates up to 3.00 kg TCOD m^{-3} day^{-1}, also showing very high nitrification activity. Ammonia uptake rate (AUR) batch test showed that biofilm nitrification activity increased when the mixed liquor SRT decreased. The final suggestion is that it is possible to run a hybrid reactor with low mixed liquor SRT values, as well as low temperatures, still having a high ammonium removal efficiency, since a large fraction of nitrification activity will take place in the biofilm.

1. Introduction

Secondary treatment of municipal wastewater is usually accomplished by biological processes that can be classified as being either suspended or attached growth. The conventional activated sludge (CAS) process can indeed present some shortcoming when exposed to high hydraulic and organic loading rates. To increase the performances of CAS systems it would be necessary building new aerobic volumes or increasing the amount of biomass inside the aerobic reactor. However, one of the major plant limitations could be related to the clarifier capacity, since additional clarifier volumes are usually difficult and expensive to obtain. As a consequence, in the last years it was proposed to combine the two different biomasses by introducing suspended carriers into the aeration/anoxic tank for biofilm attachment and growth. This is often referred to IFAS (Integrated Fixed-film Activated Sludge) process [1–3].

One of the main advantages of IFAS processes is represented by the increase of the total amount of biomass inside the system, but without a significant increase of the solid load to the final settling tank. Indeed, the biofilm is naturally retained inside the reactor, attached on the carrier elements, except the detached portion, which usually is negligible compared to the mixed liquor suspended solid (MLSS) concentration. Further, the high residence time characterizing the biofilm enhances the development of a nitrifying community [4,5] and therefore nitrification may be maintained throughout the winter, without the need of additional volumes. Indeed, the high sludge retention time (SRT) values of biofilm leads to a favorable environment for the growth of nitrifying bacteria [1]. Consequently, an IFAS process can be a suitable alternative for biological nitrogen removal and as a cost-effect option for retrofitting wastewater treatment plants (WWTPs) to sustain nitrification under low temperatures [2].

In the last years many studies have been carried out on hybrid systems in order to investigate the process efficiencies and to evaluate different carrier media performances, in terms of organic carbon and nitrogen removal [6–8]. Concerning the carrier media, it can be fixed [1,9] or freely moving inside the reactor volume [10–13]. One of the mostly used alternative is to couple the Kaldnes™ moving bed biofilm reactor (MBBR) process with a CAS system. In the MBBR process the biofilm grows attached on small carrier elements that are kept in constant motion throughout the entire volume of the reactor [14,15]. The carriers are kept inside the reactor through a sieve arrangement at the reactor outlet. Compared to fixed biofilm

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Table 1
Average operational conditions during the experimental periods.

Parameter	Units	1st period	2nd period	3rd period
Duration	days	55	50	40
Influent flow	$L h^{-1}$	24.98	23.63	26.58
RAS	$L h^{-1}$	29.23	29.25	28.30
HRT	h	3.47	3.83	3.26
SRT	days	5.73	8.51	3.42
MLSS	$mg TSS L^{-1}$	3.30	3.76	2.40
F/M	$kg COD kgTSS^{-1} day^{-1}$	0.45	0.31	0.66
DO	$mg O_2 L^{-1}$	2.16–3.25	3.37–4.66	2.96–5.02
T	°C	11.54	9.72	13.83
pH	–	7.25	7.15	7.05

Table 2
Average influent wastewater characteristics in the experimental periods.

	1st period	2nd period	3rd period
TCOD [$mg L^{-1}$]	214.50 ± 24.25	178.92 ± 68.80	205.88 ± 77.7
FCOD [$mg L^{-1}$]	111.75 ± 34.62	88.31 ± 43.98	114.20 ± 55.28
COD_{sol} [$mg L^{-1}$]	91.41 ± 32.11	87.03 ± 47.07	76.65 ± 48.22
BOD_7 [$mg L^{-1}$]	88.5 ± 81.60	85.00 ± 63.32	105.70 ± 61.25
TN [$mg L^{-1}$]	36.20 ± 9.06	33.73 ± 9.35	36.19 ± 7.90
NH_4-N [$mg L^{-1}$]	28.04 ± 8.55	21.41 ± 9.06	25.56 ± 7.24
NO_3-N [$mg L^{-1}$]	0.19 ± 0.16	0.59 ± 0.43	0.83 ± 0.30
NO_2-N	0.19 ± 0.20	0.11 ± 0.07	0.17 ± 0.10
TP [$mg L^{-1}$]	4.30 ± 1.33	4.66 ± 0.92	6.15 ± 0.97
TSS [$mg L^{-1}$]	94.7 ± 16.11	70.03 ± 31.71	72.24 ± 34.19

carrier systems, one of the interesting advantages of hybrid reactors with MBBR is the low head loss, no filter channeling and no need of periodic backwashing [16]. When used in a hybrid process, the carriers are kept in the whole of or part of the reactor volume, depending on the desired level of the treatment. The main aim of the present study was to investigate the performances of a hybrid MBBR pilot plant, when operated at different SRT values and under different temperatures, focusing in particular on the nitrification process. Based on experience in practice it was hypothesized that, with low SRT values, it would result in less nitrification taking place in the mixed liquor and more on the biofilm and that nitrification could be maintained at far lower SRT's than in CAS systems, at low temperature and with high organic loading rates applied. Ammonia uptake rate (AUR) batch tests have been performed to evaluate nitrification rate in both suspended and attached biomass in order to evaluate their respective role in the nitrification process. In this paper in particular, the results of an experimental campaign on a hybrid MBBR pilot plant are presented and discussed.

2. Materials and methods

2.1. Pilot plant description

The pilot plant was built at the Department of Hydraulic and Environmental Engineering of the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, and was fed with municipal wastewater subject to primary clarification. The pilot plant consisted of three tanks, each of 30 L, and a final 65 L settler; the layout scheme is represented in Fig. 1. The first and third aerobic reactors (in the following respectively referred to AS1 and AS2) were conventional pure suspended biomass systems, while the second aerobic reactor (in the following referred to HYB) was filled with the Kaldnes^{TM} K1 carriers, with a 60% filling fraction, corresponding to a net surface area in the HYB reactor of $300 m^2 m^{-3}$; for further details on the characteristics of the adopted carriers, the reader is referred to the literature [12]. Mixing in the reactors was provided by coarse-bubble aeration systems, while special sieve arrangements were adopted to retain the carriers inside the HYB reactor.

The municipal wastewater was pumped from the city sewer system and stored into a load equalization basin, in order to secure a quite constant pollutants concentration during the day. Further, the wastewater was pumped into a primary settling tank from which it was fed to the pilot plant. The overall field campaign, which duration was nearly 150 days, was divided into three experimental periods, each characterized by a different SRT value; in Table 1, the average operational conditions in the three experimental periods are reported.

In order to enhance biofilm development on carrier media, the pilot plant was continuously fed for about one month before starting the field campaign. No particular problems were experienced during the experimental periods, except for some foaming at the beginning of the start-up phase, completely disappeared after almost one week of operations. In Table 2, the average influent wastewater characteristics are reported.

2.2. Analytical methods

Grab samples were taken three times a week and analyzed for total nitrogen (TN), ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), total COD (TCOD), filtered COD (FCOD), truly dissolved COD (COD_{sol}) and every working day for total suspended solids (TSS) and volatile suspended solids (VSS). All the analyses were carried out according to Standards Methods [17] except COD_{sol} that was analyzed according to the protocol proposed by Mamaïs et al. [18]. Periodically, BOD_7 was determined as a control of the pilot plant behavior.

Periodic test on carrier samples were carried out, in order to establish the biofilm growth on the carriers; briefly, a 20 carriers sample was taken from HYB reactor, dried in a oven for one night at 105 °C and then weighted (W_1). After biofilm was removed, the carriers were dried another night at 105 °C and then weighted again (W_2); the amount of the attached biomass was then calculated as $W_1 - W_2$.

Ammonium uptake rate (AUR) batch tests were performed to evaluate the nitrification rates of both suspended biomass and biofilm from the HYB reactor, by adopting a modified procedure derived by Kristensen et al. [19]; for further details referring to biofilm measurements as well as AUR test the reader is addressed to the literature [12].

Sludge settleability was determined by the sludge volume index (SVI) test, carried out on biomass samples taken from HYB reactor, according to the protocol reported in the technical literature [20].

Microscopic observations were carried out for the evaluation morphological floc characteristics as well as to observe the potential effects caused by carriers on floc structure. Observations were made at 100× and 1000× magnifications.

3. Results and discussion

3.1. Organic carbon removal

The pilot plant showed high COD removal efficiencies throughout the experimental campaign, even in the 2nd period, characterized by the lowest temperature values, lower than 9 °C for many days and by lower pollutant concentrations, likely due to the snow melting occurring in that period. Nevertheless, it has to be stressed that the SRT variation did not affect in a considerable way the pilot plant behavior in terms of COD removal (total and filtered), as well as of BOD_7. In Fig. 2 the COD loading rates applied and removed are reported, referring to each experimental period. The bisector line indicates the 100% removal efficiency. It can be noticed that the pilot plant was capable to remove the substrate also at higher loading rates in terms of TCOD, up to