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LOW SLUDGE AGE AND ITS CONSEQUENCES FOR METABOLISATION, STORAGE AND ADSORPTION OF READILY BIODEGRADABLE SUBSTRATE (S_S)

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ABSTRACT

In lab-scale experiments with sludge from a 2-stage activated sludge system (AB process) it is shown that the inert soluble COD fraction of the wastewater is always significantly higher if the wastewater is added to A-sludge (SRT ca. 0.5 d) in comparison to B-sludge (SRT ca. 20 d). At the same time the readily biodegradable COD (S_S) is lower with A-sludge, which showed neither adsorption nor storage of S_S. It is hypothesised that very low sludge ages result in selecting fast growing bacteria, which can utilise only part of the S_S in the raw wastewater. The other part of S_S remains in the wastewater and can be utilised for enhanced denitrification in the second stage. The key for a successful modelling of processes with a sludge age lower than 1 day is to make the wastewater characterization for COD and some of the important kinetic parameters dependent on sludge age.

KEYWORDS

Activated Sludge, Adsorption, Mathematical Modelling, Respirometry, Sludge Age, Storage

INTRODUCTION

According to the Activated Sludge Model No.1 (ASM1) (Henze *et al.*, 1987) it is assumed that in wastewater treatment plants (wwtp) with a sludge age longer than 5 days the biodegradable fractions can be modelled as a single substrate and a single removal kinetic (one Monod term). If the sludge age, however, decreases to 1 day and below, the assumptions of the ASM 1 with respect to COD removal may not be applicable any more.

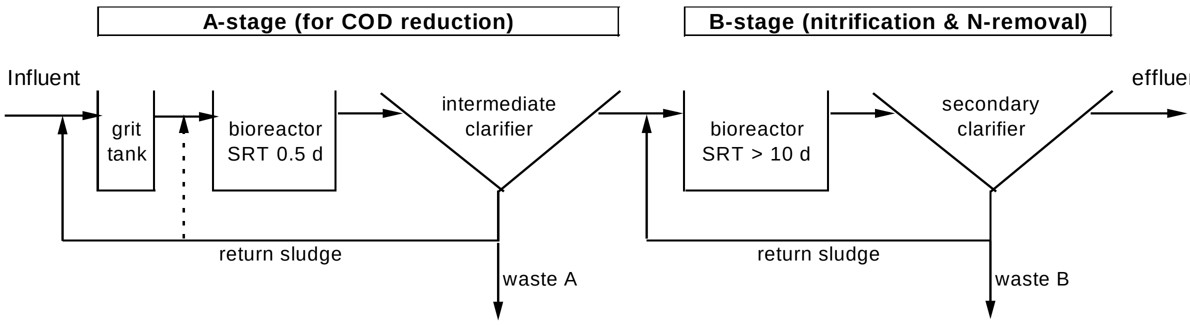

Figure 1: Flow-chart of a 2-stage WWTP with separate biocoenoses of different sludge age (SRT) following the AB technology

At 2-stage activated sludge plants like the AB-system (Böhnke, 1977), for example, it is expected that almost no readily biodegradable COD (S_S) will leave the first stage, if fully aerated, as the heterotrophic biomass should be able to metabolise the S_S completely. This assumption is in contradiction to literature reports (Bili, 1996; Böhnke *et al.*, 1998) which claim that mainly particulate

COD is eliminated in the aerobic A-stage. Unfortunately most of the research done on AB-technology is based on BOD, COD_{tot} and $COD_{0.45\mu}$ measurements. In an attempt to find a dynamic model for the A-stage, the role of SS was discussed by Otterpohl (1995), who hypothesized that S_S is partly adsorbed to the biomass. Freund et al. (1996) concluded from simulation studies, that the soluble substrate in the influent of the A-stage has to be divided into a readily and a slowly biodegradable substrate. To get more insight into the fate of S_S in an A-stage and in systems with very low sludge age in general, special research was undertaken in the last years, focusing on the extent of metabolisation and the role of adsorption and intracellular storage of S_S.

MATERIALS AND METHODS

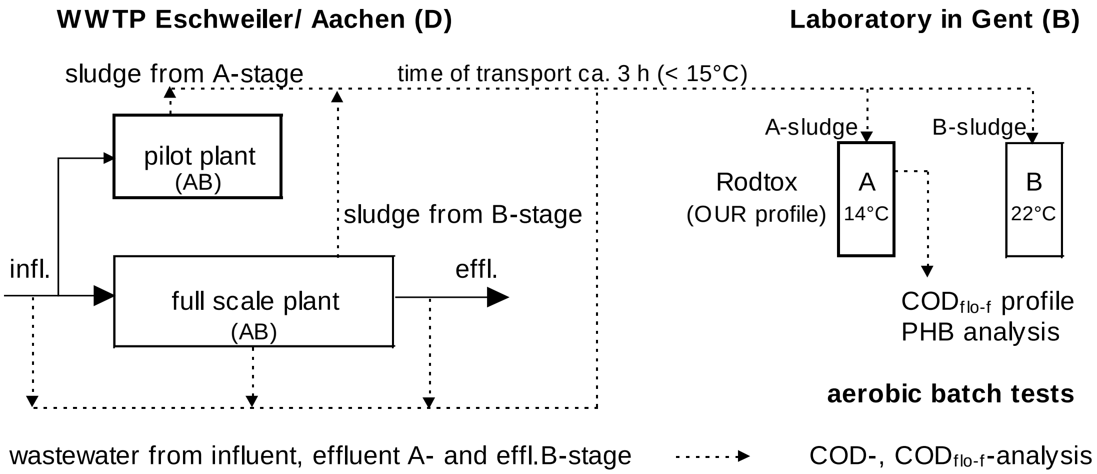

Figure 2: Experimental design

The WWTP Eschweiler is designed and operated according to the AB-technology as shown in Figure 1. A pilot plant helped to prepare the upgrading of the plant. Sludge and wastewater were taken from different locations within the pilot and the full scale plant (Figure 2) and then brought to Ghent University (Belgium), where the laboratory tests were started immediately. They included respirometry as well as physical and chemical methods for characterisation of sludge behaviour and wastewater.

Respirometry to observe metabolisation and estimate S_S

The aerobic batch tests were performed with the RODTOX respirometer (Vanrolleghem *et al*., 1994). The biological reactor is continuously aerated under constant air pressure and volume. Temperature was controlled at 14°C. From the change of O_2 concentration after substrate addition the oxygen uptake rate (***OUR***) of the sludge was calculated. The k_La-value of the aeration system needed for the ***OUR*** calculation was estimated according to standard methods, described in Haider, 2000.

Cyanide for adsorption test

In order to see whether adsorption of soluble COD occurs with A-sludge, a certain amount of bio-toxicant cyanide was added to the batch reactor prior to substrate addition to exclude any kind of biological activity. Samples were drawn from the bioreactor at regular intervals and the concentration of soluble COD (COD_{flo-f}, see below) over time was measured.

Flocculation-filtration method for estimating S_S and S_I

To be able to follow the S_S concentration in the batch reactor after substrate addition and to estimate S_I the flocculation-filtration method according to Mamais *et al*. (1993) and Wentzel and Ekama (1995) was applied. Mamais *et al*. (1993) performed a number of S_S estimations on different municipal wastewaters using the flocculation-filtration method as well as the aerobic batch test according to Ekama *et al*. (1986) and found a very good correlation. Instead of Zn-sulphate, as used by Mamais *et al*. (1993), Al-sulphate was used for flocculation as suggested by Wentzel and Ekama (1995).

Analyses of PHB for estimating intracellular storage

To estimate the effect of intracellular storage of substrate, the PHB (Polyhydroxybutyrate) content of the biomass in the batch-reactor was followed during the experiment (in parallel to the ***OUR*** curve). The analyses of the storage polymer PHB were done on the TSS residue after filtering the sludge samples at the Laboratory for Technical Chemistry and Environmental Engineering, Ghent University using the method described in Baetens *et al*. (1999).

RESULTS

Physical adsorption of S_S or S_I on the biomass: In none of the 4 batch tests with cyanide adsorption of $COD_{flo\text{-}f}$ was observed. The $COD_{flo\text{-}f}$ concentration after wastewater addition corresponded well with the theoretical concentration calculated from dilution and did not change within ca. 1 hour. It is therefore concluded that neither adsorption of S_S nor S_I does occur.

Intracellular storage of S_S : According to the increase of PHB less than 10 % of the S_S of the wastewater added to the A-sludge was stored within the cells. The effect of storage on the ***OUR*** and $COD_{flo\text{-}f}$ profiles of the batch tests could therefore be neglected.

Metabolisation of S_S : The main result from the respirograms and $COD_{flo\text{-}f}$ -profiles, as shown for one batch test in Figure 3, is that a relatively high concentration of soluble COD remains in the batch reactor and little readily biodegradable COD (5 - 10 % of COD_{tot}) is metabolised.

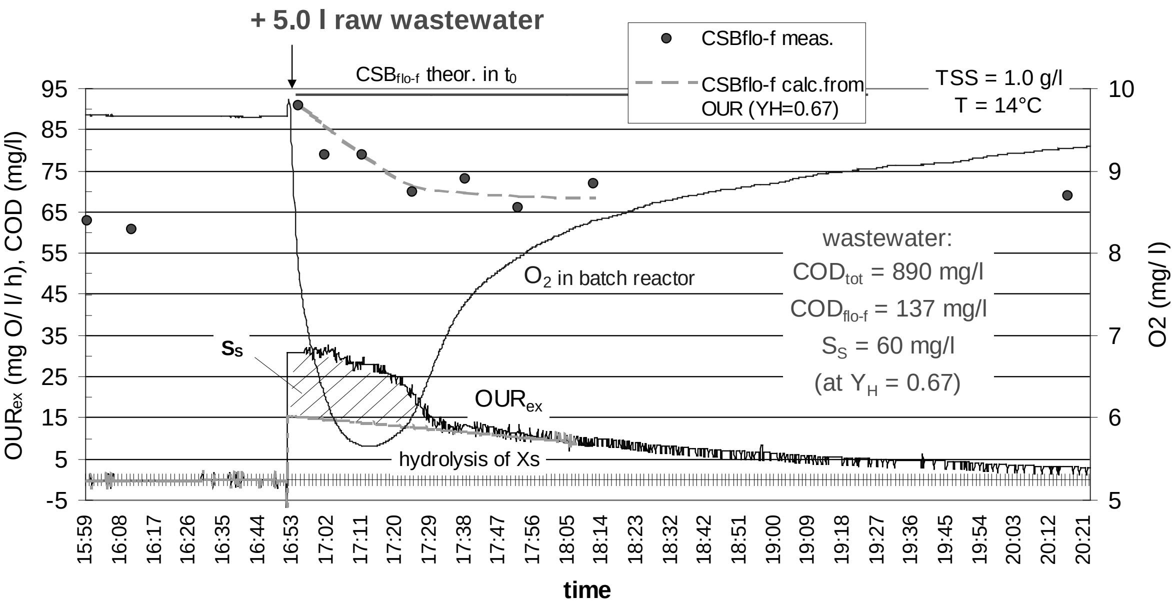

Figure 3: Aerobic batch test with A-sludge and raw wastewater
(OUR_{end} is not shown in the respirogram as the equilibrium oxygen concentration (O_2 supply matches O_2 consumption due to constant endogenous respiration) is used for the calculation of OUR_{ex})

Figure 3 shows the change of the O_2 concentration in the batch reactor (7.0 l A-sludge) after addition of wastewater (5.0 l). According to the exogenous respiration rate (OUR_{ex}) the S_S in the wastewater was ca. 60 mg/l. According to the $COD_{flo\text{-}f}$ concentration (137 mg/l) and the S_I concentration (35 mg/l) estimated for this wastewater, however, the total S_S concentration should be ca. 100 mg/l. Hence, part of the S_S seems to be inert for the A-sludge or so slowly biodegradable that it can not be detected in the respirogram. Clearly evident is the hydrolysis of X_S during the experiment.

As the removal of COD_{flo-f} by adsorption and storage (less than 10 %) can be neglected, as described above, the S_I concentration of the raw wastewater according to A-sludge (SI_A) can be calculated from the COD_{flo-f} concentrations as followed:

$$SI_A = (SI_R\ (t_{end}) * (V_R + V_{ww}) - SI_R\ (t_0) * V_R) / V_{ww}$$

SI_R (t_0): S_I in the bioreactor before substrate addition, $COD_{flo-f} = S_I$
SI_R (t_{end}): S_I in the bioreactor at the end of the batch test, when S_S is degraded, $COD_{flo-f} = S_I$
V_R; V_{ww} : Volume of sludge in bioreactor at t_0; volume of wastewater added

For the batch test in Figure 3 this calculation gives SI_A = 81 mg/l. Adding SI_A and SS_A, estimated from ***OUR,*** we get a theoretical concentration for COD_{flo-f} in the wastewater at 140 mg/l, which is very similar to the measured COD_{flo-f} concentration (137 mg/l). This supports the assumption that $COD_{flo-f} \cong S_S + S_I$. The theoretical COD_{flo-f} concentration during the experiment, calculated by continuously subtracting the amount of S_S degraded according to ***OUR*** from the initial COD_{flo-f} concentration after substrate addition, corresponds with the ***OUR*** curve, as shown in Figure 3.

Figure 4 shows all estimated soluble inert COD concentrations for A-sludge (SI_A) and for B-sludge (SI_B) respectively and the COD_{flo-f} concentrations of the raw wastewaters used for the batch tests. All of the 8 batch tests performed show a similar behaviour: SI_A is much larger than SI_B ($SI_A \cong 2 * SI_B$). The SI_B concentrations were estimated by measuring the COD_{flo-f} concentrations in the effluent of the full scale plant as well as from several S_I estimation tests using B-sludge. The amount of SI_B was between 4 and 5 % of the total COD of the raw wastewater.

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Figure 4: COD_{flo-f} , SI_A and SI_B of wastewaters added to aerobic Batch-tests with A-sludge

If the assumption that $COD_{flo-f} \cong S_I + S_S$ is true, the conclusion from the above is that the S_S concentration of the raw wastewater according to A-sludge (SS_A) is always smaller than the total S_S concentration according to B-sludge (SS_B).

$$SS_A < SS_B$$

In Batch tests, where acetate was given to A-sludge, all substrate was metabolised. All respirograms, however, showed a continuous increase of OUR before it reaches a maximum. If acetate was given to B-sludge, the maximum (plateau) was reached immediately after acetate addition. It is concluded that an adaptation of A-sludge to acetate is necessary because a smaller metabolic potential is available in this sludge due to the shorter sludge age. It supports the hypothesis that SS_A is smaller than SS_B.
A COD- and N-balance for the pilot plant showed that the oxygen consumption in the A-stage was responsible for only 18 % of the COD removal in this stage (50 % of total). It is therefore concluded that a significant amount of S_S left the A-stage, supporting the above hypothesis. The overall N-elimination efficiency of the plant (at 12°C, however no supernatant returned from the sludge treatment) reached 80 % of total N in the influent. The B-stage removed 75 % of N_{tot} in the influent of the B-stage at a SRT = 19 days and at a relatively low ratio of $COD_{infl.B}$ / $N_{infl.B}$ at 6.0. At the same time only 40 % of the removed COD in the B-stage was transformed into waste sludge.

DISCUSSION

Based on the observation from aerobic batch tests that readily biodegradable COD (S_S) estimated from respirograms with A-sludge (SRT about 0.5 days) is smaller than the estimated total S_S in the wastewater according to B-sludge (SRT about 20 days), it is hypothesised that the availability of readily biodegradable substrate S_S changes with sludge age if sludge age is below about 1 day. The most likely explanation is that low sludge age operation selects fast growing bacteria, which can utilise only part of the S_S in the raw wastewater. The other part of S_S remains in the wastewater or, if sludge age is increasing, is metabolised at a lower rate.

For these reasons it is obvious that the key for an optimal operation of an AB-plant, i.e. maximising the N-removal of the system, lays in the control of the aerobic sludge age in the A-stage. The key for a successful modelling of low sludge age processes in general is to make the wastewater characterization for COD and some of the important kinetic parameters dependent on sludge age.

ACKNOWLEDGEMENT

This research was financially supported by the Oswald-Schulze-Stiftung, Germany, and (in part) by the Fund for Scientific Research - Flanders (FWO), Belgium. It was a common project with the *Institut für Siedlungswasserwirtschaft* (ISA) (project coordination) and the *Forschungsinstitut für Wasser und Abfallwirtschaft* (FiW) (operation of the pilot plant in Eschweiler), both Technical University (RWTH) Aachen.

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