Turn it up! High-load Contact Stabilization (HiCS) is a valuable activated sludge process for maximizing sludge production from sewage

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Abstract
The conventional approach of wastewater treatment is to maximize effluent quality and minimize operation costs, but this limits the amount of energy that could potentially be recovered. In order to proceed to an energetically self-sustaining wastewater treatment, engineers have taken renewed interest in pre-treatment processes that divert the organics present in the water into well-digestible sludge. In this study, we hypothesize that a High-load Contact Stabilization (HiCS) process is suitable for pre-treating domestic sewage to maximize sludge production. We compared the performance of HiCS to an established high-load process, the so-called A-stage of the 'Adsorptions-Belebungsverfahren'. The HiCS reactor obtained an average removal efficiency of 34±10% total COD and 66±5% dissolved COD. The A-stage performed similarly, with a removal of 35±17% total and 77±3% dissolved COD. In both systems, specific oxygen utilization rates rose and dropped back to near baseline levels within 30 min. aerobic contact time, suggesting that aerobic substrate removal occurs primarily in the early stages of the contact period. Sorption experiments with HiCS sludge showed a fast removal of soluble and particulate substrate within the first min. of contact time. Conversely, sorption experiments with A-stage sludge showed a more gradual and variable pattern of substrate removal. These results indicate that the HiCS sludge is better adapted to quickly remove substrates via sorption than A-stage sludge and may therefore be more suitable for further optimization of sludge production for a maximal recovery of energy.

Keywords
AB process; Biosorption kinetics; Energy recovery

INTRODUCTION

Following adequate water purification, resource recovery is the new visionary goal for wastewater treatment, inspiring a search for technologies that not only remove energy and resources but make them available for reuse. Any technology that aims to recover energy from wastewater needs to (1) minimize energy loss by avoiding extensive oxidation of organic matter to CO_2, (2) facilitate efficient conversion of energy by fractionating the wastewater into a thick stream of concentrated organics and a diluted effluent stream and (3) operate in an energy-efficient manner and allow for close process control. In recent years, high-load activated sludge processes have gained attention because of their efficient concentration of organics into a well-digestible sludge, prior to further treatment of the water stream for nutrient removal. A well-known example of such a high-load system is the A-stage of the 'Adsorptions-Belebungsverfahren' or AB process (Böhnke, 1977), which is designed for rapid removal or organic materials at high sludge loading rates (2-10 gBOD $gVSS^{-1}$ d^{-1}) and low sludge retention times (hours to days). A short hydraulic retention time of less than 30 min. selects for rapid removal of organic matter and typical removal efficiencies range from 50 to 70%.

A novel promising technology for energy recovery from wastewater is a High-load Contact Stabilization (HiCS) process. In its original design at conventional loading rates, the Contact

Stabilization (CS) process consists of a contact tank in which return sludge is mixed with influent for a short contact time – 15 to 60 min. – and substrate is removed via rapid degradation, sorption or storage. After settling, effluent is discarded and the sludge is sent to a stabilization tank where additional respiration occurs for at least 1.5 hours (Coombs, 1921). As a high-load version of the CS process, HiCS may provide advantages over other high-load processes such as the A-stage. CS has a high intrinsic resistance to toxic shocks and a low aeration tank volume (Bunch & Griffin, 1987). Whereas the contact tank may or may not be aerated, most of the oxidation occurs in the aerated stabilization tank, which gives a competitive advantage to micro-organisms adapted to quickly store or adsorb substrates for later metabolization after settling. Recent studies show a reappreciation of the CS process and it was suggested that HiCS performs better than the A-stage (Huang & Li, 2000), although a systematic experimental comparison has not yet been performed.

In this study, a HiCS system was developed and compared with the A-stage for the removal of organic substrates from black water. The two systems were operated at laboratory scale at high sludge loading rates and low sludge age, both with and without addition of iron chloride as flocculant to improve settleability and phosphate removal. Additional batch tests were performed to compare oxygen consumption rates, sorption kinetics and sludge digestibility. This paper demonstrates the feasibility of HiCS for wastewater treatment from an energy recovery viewpoint.

MATERIALS AND METHODS

Continuous and batch experiments

Black water was collected weekly for a period of 80 days (between May and July 2013), sieved (1 mm) and diluted to match average concentrations of chemical oxygen demand (COD) of Flemish wastewater. Average values and standard deviations were 270±70 mg L^{-1} total COD, 160±40 mg L^{-1} dissolved COD, 140±30 mg L^{-1} total BOD, 75±15 mg L^{-1} Kjeldahl-N, 71±15 mg L^{-1} NH_4^+-N, 6.4±1.5 mg L^{-1} PO_4^{3-}-P and pH 7.7±0.2. A schematic representation of the HiCS and A-stage system is given in **Figure 1**. Average loading rates were 4.8 gCOD $gVSS^{-1}$ d^{-1} for HiCS and 3.3 gCOD $gVSS^{-1}$ d^{-1} for the A-stage.

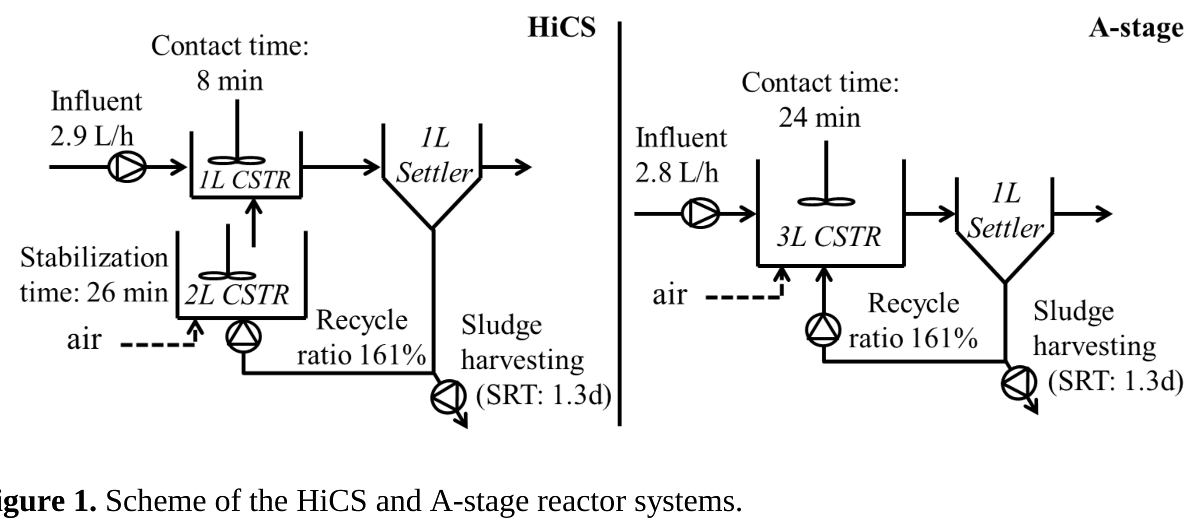

Figure 1. Scheme of the HiCS and A-stage reactor systems.

Sludge inoculum was obtained from the A-stage of the WWTP of Breda (NL). After 47 days, continuous addition of Fe_3Cl was started in both systems at a Fe:P molar ratio of 0.5.

For batch tests, HiCS and A-stage sludge were taken from steady-state reactors. To determine the specific oxygen uptake rate (SOUR), the sludge was continuously aerated and small samples were placed in a non-aerated sealed container every 10 min. Dissolved oxygen concentrations were measured at intervals of 30 sec, both for undiluted sludge (endogenous respiration) and with addition of substrate at a ratio of 2:1 substrate:sludge. The SOUR was calculated as the decline in DO per unit of time divided by the sludge concentration. For adsorption experiments, HiCS and A-stage sludge were centrifuged (2 min. at 2000 x *g*) and resuspended in distilled water at a pH of 8.5. The substrate consisted of reactor influent filtered over a 14 µm filter in order to distinguish substrate from sludge, since nearly all of the sludge particles had a size >14 µm (data not shown). The substrate was added to the sludge in a ratio of 2:1 in a stirred but non-aerated container. At different time points, samples were taken and immediately filtered over a 14 µm filter to determine the amount of free substrate and a 0.2 µm filter to determine the amount of soluble substrate.

RESULTS AND DISCUSSION

Reactor performances are given in **Table 1**. **Figure 2** represents the sludge yield of both systems before and after addition of flocculant.

Table 1. Volumetric COD removal rates ($g\ L^{-1}\ d^{-1}$) and standard deviations for the HiCS and A-stage systems.

		COD_{tot}	COD_{diss}
HiCS	No $FeCl_3$	2.46 (0.8)	2.93 (0.42)
	$FeCl_3$	1.37 (1.09)	2.06 (0.3)
A-stage	No $FeCl_3$	2.43 (1.45)	3.33 (0.46)
	$FeCl_3$	0.89 (1.01)	2.05 (0.32)

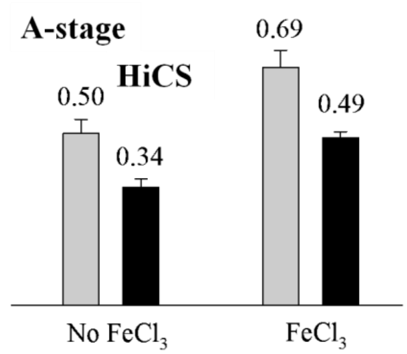

Figure 2. Sludge yields ($gVSS\ gCOD^{-1}$) for the HiCS and A-stage systems.

The removal rate of dissolved COD lay well within expectation and demonstrated the equivalence of the HiCS system with other high-load systems. The lower removal efficiencies for total COD were due to the periodic washout of non-settled sludge, indicating the importance of efficient sludge separation. As expected, nitrogen and phosphorus compounds left the reactors quasi unaltered, which potentially allows nutrient recovery in subsequent treatment stages. Addition of flocculant ($FeCl_3$) improved phosphorus removal at stoichiometric amounts. Sludge yields exceeded values encountered in conventional activated sludge systems (typically in the order of 0.15 $gVSS\ gCOD^{-1}$) by a factor two to five, indicating the subsequent potential for energy recovery by means of high-load wastewater treatment systems. The sludge volume index (SVI) did not notably decrease after flocculant addition, which shows that the sludge settleability was mainly determined by other factors.

Batch experiments revealed that, upon addition of substrate, the SOUR increased by a factor five in the HiCS sludge and a factor nine in the A-stage sludge, and dropped back to near baseline levels after 30 to 40 min. of aeration (**Figure 3**). This suggests that aerobic substrate removal occurs primarily within the early stages of contact with the sludge. Sorption experiments (**Figure 4**) showed a fast removal of soluble and particulate substrate within the first min. of contact with HiCS sludge, followed by a slower removal during the remainder of the experiment. In contrast, substrate profiles for the A-stage sludge were more variable and showed a more gradually declining trend. These findings indicate that the HiCS sludge has a different substrate use strategy than A-stage sludge and is adapted to quickly remove substrates within the first min. of contact time, presumably via sorption or intracellular storage, before aerobic degradation occurs. Given a careful control of substrate contact times, the HiCS system may therefore be better suited than the A-stage sludge for the optimization of sludge production toward maximal recovery of energy.

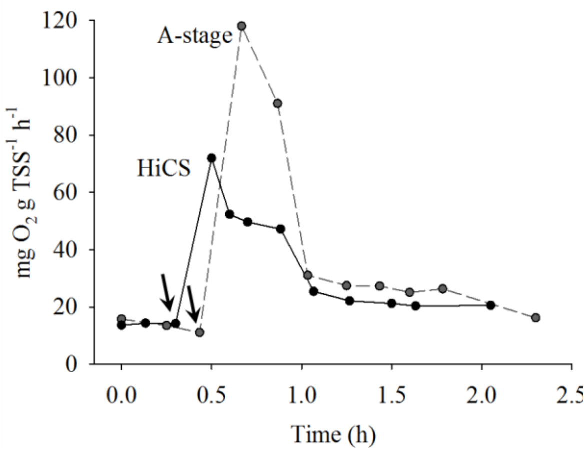

Figure 3. SOUR profiles for HiCS and A-stage sludge after addition of influent. The arrows indicate time of substrate addition.

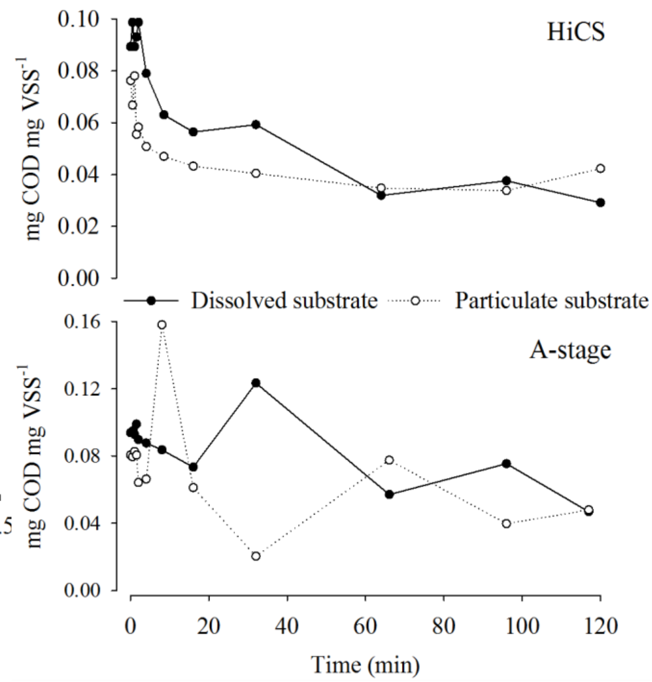

Figure 4. Adsorption profile of soluble and particulate substrate for HiCS and A-stage sludge.

In conclusion, our experiments demonstrate the promising potential of HiCS as a high-load activated sludge system for pretreatment of wastewater to maximize sludge production and optimize conservation of chemical energy. Subsequent study will focus on further optimizing reactor performance and integrating this technology in an overall treatment scheme, thus advancing to an energetically self-sufficient wastewater treatment.

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