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The sequencing batch reactor as an excellent configuration to treat wastewater from the petrochemical industry

Short title: The SBR as an excellent configuration to treat wastewater from the petrochemical industry

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Abstract

In the present study, the influence of a changing feeding pattern from continuous to pulse feeding on the characteristics of activated sludge was investigated with a wastewater from the petrochemical industry from the harbour of Antwerp. Continuous seed sludge, adapted to the industrial wastewater, was used to start up three lab-scale sequencing batch reactors. After an adaptation period from the shift to pulse feeding, the effect of an increasing organic loading rate (OLR) and volume exchange ratio (VER) were investigated one after another. Remarkable changes of the specific oxygen uptake rate (sOUR), microscopic structure, sludge volume index (SVI), SVI_{30}/SVI_5 ratio, and settling rate were observed during adaptation. sOUR increased 2 to 5 times and treatment time decreased 43% in 15 days. Stabilization of the SVI occurred after a period of 20 days and improved significantly from 300mL.g^{-1} to 80mL.g^{-1}. Triplication of the OLR and VER had no negative influence on sludge settling and effluent quality. Adaptation time of the microorganisms to a new feeding pattern, OLR and VER was relatively short and sludge characteristics related to aerobic granular sludge were obtained. This study indicates significant potential of the batch activated sludge system for the treatment of this industrial petrochemical wastewater.

Keywords: activated sludge adaptation; carbon removal kinetics; sequencing batch reactor; settling characteristics; specific oxygen uptake rate

Introduction

The continuous-flow conventional activated sludge system (CAS) is the main type of biological wastewater treatment system for the removal of carbon, phosphorus and nitrogen from domestic and industrial wastewater. CAS has been successful for the treatment of various types of wastewater, although the system is well known for sludge settlement limitations due to the presence of filamentous microorganisms (Martins et al. 2004).

The feeding pattern was mostly investigated to prevent filamentous bulking and to obtain better settling properties (Chudoba et al. 1973). In earlier research, using synthetic wastewater with acetate, bactopeptone or glucose as carbon source, it was demonstrated that changing the feeding pattern significantly improved the settling characteristics of AS (Ciğgin et al. 2011; Cubas et al. 2011; Guo et al. 2014). All studies described better settling properties when the feeding time was as short as possible (pulse feeding) and the substrate gradient was as high as possible. More in detail, the research of Martins et al. (2004) showed clearly the impact of the feeding time on the sludge characteristics using acetate as substrate. Promoting a strong substrate gradient in the SBR with an aerobic fill time ratio (AFTR) lower than 5.4% resulted in good settling sludge (SVI < 120 mL.g^{-1}). Whenever acetate was added in a limiting rate with an AFRT > 6.2%, a condition in which acetate concentration in the reactor was always very low, the sludge settling deteriorated (SVI between 150 mL.g^{-1} and 500 mL.g^{-1}). To conclude, sludge settling could be improved by changing the feeding strategy to a pulse feed in this research. Ciğgin et al. (2011) reported a SVI of almost 500 mL.g^{-1} during operation under continuous feeding. After a shift from continuous to pulse feeding, the sludge settling property quickly improved to a SVI < 120 mL.g^{-1}.

Since the 1970s, a real revolution happened in wastewater treatment processes. Advanced bubble diffusers were developed and more energy efficient material, like pumps, valves and mixers were designed. Also PLC's and automation software were developed. Thanks to this development, integrated real time control of the sequencing batch reactor (SBR) became possible (Wiese et al. 2005; Simon et al. 2006; Shaw et al. 2009; Dries 2016). Despite this industrial development, the real success of the SBR system remains off (Artan et al. 2001).

Different reasons can be formulated for the absence of a general accepted use of the SBR technology. Firstly, in the authors opinion, a "lack of knowledge" is still present in literature about the treatment of industrial wastewater with SBRs. Secondly inhibition of sludge due to toxic components in the influent is discussed as a reason to not use SBRs (De Schepper et al., 2010; USEPA, 1991). Furthermore, the CAS configuration is seen as a safe operation mode in industry. Although different disadvantages, like poor settling characteristics, the absence of flexible process control and low performance for shock loading are known, the system is still widely used. Lastly, the role of the feeding pattern for the treatment of industrial wastewaters is a topic that is still largely unexplored in literature which is in contrast to the amount of studies on synthetic wastewater. However, this could deliver important information about the operation mode of treatment systems.

The objective of the current study is formulated in function of the reasons mentioned above. Firstly, adaptation of AS from continuous to batch feeding for industrial wastewater was investigated. After the adaptation period, the total performance of the system was investigated. The sludge selected, originated from a chemical company in the harbour region of Antwerp (Belgium), and was characterized by poor settling properties.

The most important research gaps that can be filled with this research are (i) Can AS adapt to a changing feeding pattern of petrochemical industrial wastewater and how long does it take to adapt? (ii) How will the microbial kinetics and the physical variables changes during adaptation? (iii) Can the treatment efficiency be increased by changing the organic loading rate (OLR) and the volume exchange ratio (VER)?

Methods

Reactor set-up

Experiments were conducted using three identical, completely automated lab-scale SBRs. Respectively called SBR 1, 2 and 3. The working volume of the reactors was 13L with a VER of 30% to 60% and a fill time ratio lower than 1%. Every cycle, 4 to 8L of wastewater was added to each SBR with an internal diameter of 230 mm.

A Siemens (Germany) programmable logic controller (PLC), type CPU 319-3PN/DP, controlled the reactor. Configuration of this PLC was done with Siemens Simatic Step7 software. LabViewTM (National Instruments, Austin – Texas, United States of America) was used as user interface to change reactor settings and to visualise the process. This software was also used for data capture and data transfer to MS Excel.

The dissolved oxygen (DO) concentration in the reactors was monitored with a Hach Lange LDO sc sensor. pH and oxidation reduction potential (ORP) were measured in the reactors with Jumo TecLine sensors. Sensor signals were transferred by a process field bus (profibus) from a Hach Lange sc 1000 module to the PLC.

Reactor operation

The reactors were operated in three different stages, described in Table 1. At the beginning of stage I, reactors were inoculated with the industrial seed sludge. During stage I, adaptation of the sludge to a new feeding pattern was investigated. Sludge was fed once a day with 4L of wastewater. At the end of stage I, the sludge of the three reactors was mixed and divided again in the reactors. In stage II the OLR was varied between the reactors. The operation of SBR 1 was not changed, compared to stage I. The cycle time of SBR 2 and 3 was lowered to have 2 and 3 feedings a day of 4L each with a corresponding number of 2 and 3 cycles a day respectively. This resulted in a doubling and tripling of the organic loading rate for SBR 2 and 3. At the end of this period, sludge of SBR 2 and 3 was mixed and divided again in SBR 2 and 3. After the mixing, both reactors were subjected to a different VER. SBR 2 was operated with 2 cycles a day with each feeding 4L of wastewater. SBR 3 was operated with 1 cycle a day with a feeding volume of 8L. Reactor 1 was not further used in stage III.

Table 1. Operating conditions of the lab-scale SBRs during stage I, II and III

Stage	**Operation days**	**Reactor**	**Phase (duration (min))**						**Total cycle time (h)**	**Feeding volume/ cycle**
			Pre-aeration	**Feeding (with mixing)**	**Aerobic reaction**	**Excess sludge withdrawal**	**Settling**	**Effluent discharge**		
Stage I	154	SBR1	30	2	1283	3	120	2	24	4 L
		SBR2								
		SBR3								
Stage II	220	SBR1	30	2	1283	3	120	2	24	4 L
		SBR2	15	2	639	2	60	2	12	4 L
		SBR3	10	2	425	1	40	2	8	4 L
Stage III	75	SBR2	15	2	639	2	60	2	12	4 L
		SBR3	30	4	1280	4	120	2	24	8 L

Dissolved oxygen concentration in the reactors was controlled between a lower and upper DO set point of 1.5 and 5.0 mg $O_2.L^{-1}$ respectively. In Labview^{TM}, data pairs of time and DO concentration were made during the air-off period to calculate the oxygen uptake rate by performing a linear least-square regression analysis.

The pH in the reactors was kept between 7.7 and 8.8, using a sodium hydroxide solution of 3 $mol.L^{-1}$. The SRT was kept constant at 30 days, which is the same SRT as in the full scale industrial plant. SRT was regulated by removing a volume of 430 mL excess sludge every day. Temperature was kept at room temperature which was always between 18°C and 22°C.

Sludge & influent

The seed sludge and influent wastewater used in this study were obtained from a petrochemical company located in the harbour region of Antwerp. The full scale WWTP is a continuously fed AS system. The sludge retention time (SRT) of this WWTP is kept at 30 days for optimal carbon removal. The food to mass ratio (F/M) of the industrial installation is approximately 0.25 $kgCOD.kgMLVSS^{-1}.d^{-1}$.

During this study, thirteen different influent batches were used. The batches were taken from a buffer tank before AS treatment. Table 2 summarizes the most important parameters of the influent wastewater used in the current study. All influents were stored at 4°C to minimize biological reaction, but were given time to equilibrate to laboratory temperature before feeding to the reactors.

Table 2. Composition of the influent batches used during stage I, II and III

Stage	Batch	day	COD (mg $O_2.L^{-1}$)	sCOD (mg $O_2.L^{-1}$)	Total nitrogen (mg $N.L^{-1}$)	PO_4-P (mg P $.L^{-1}$)	Chloride (mg$.L^{-1}$)	Conductivity (mS$.cm^{-1}$)	pH
I	1	1 - 39	1900	1850	10.4	0.42	3100	13.1	8.00
	2	40 - 87	1680	1640	10.6	0.29	3350	11.1	7.50
	3	88 - 144	1728	1680	5.0	0.35	3250	11.3	6.95
	4a	144 - 154	1842	1820	3.0	0.50	3500	12.0	7.08
II	4b	155 – 181							
	5	182 – 212	1500	1480	0.9	0.70	2000	12.1	7.10
	6	213 – 244	1890	1820	0.5	0.50	3000	13.1	6.80
	7	245 – 275	1940	1796	0.3	1.00	3500	12.8	7.30
	8	276 - 313	1680	1625	0.6	1.10	4000	13.7	7.02
	9	314 – 343	1600	1580	0.6	0.90	3500	10.1	7.15
	10	344 – 374	1252	1180	0.4	1.20	2400	9.5	7.47
III	11	375 – 402	1504	1464	0.6	1.35	3500	12.0	7.53
	12	403 – 433	1290	1196	0.7	1.30	3550	12.2	7.82
	13	434 - 450	996	950	0.6	1.30	3550	12.4	7.41
Average and standard deviation			1600 ± 285	1544 ± 283	2.6 ± 3.7	0.8 ± 0.4	3246 ± 530	11.9 ± 1.2	7.3 ± 0.3

Nutrients were added to satisfy the nutritional requirements of biomass in a ratio of 100:5:0.8 as COD/N/P (Eckenfelder et al. 2008). To avoid nitrification and associated oxygen consumption, nitrogen was added as KNO_3 instead of the commonly used NH_4^+.

Phosphorus was added as K_2HPO_4.

Analytical methods

The chemical oxygen demand (COD) was measured with Hanna Instruments (HI) (Belgium, Temse) COD Tests HI 93754A-25 low range and HI 93754B-25 medium range tubes. Total nitrogen was measured with the HI 94767A-50 test and chloride concentration with the HI 3815 test kit, both from Hannah Instruments. pH and conductivity were measured with the HI 9023 microcomputer pH meter, respectively HI 9033 multi range conductivity meter. Phosphorus was measured using PhosVer3 powder pillows from Hach Lange (Belgium, Mechelen).

Sludge volume (SV), sludge volume index (SVI), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were measured in accordance with the procedures described in Standard Methods for the Examination of Water and Wastewater (1998). Settling rate, SV and SVI were determined with a 1L graduated cylinder with a height of 34.5cm and an internal diameter of 6.1cm. Sludge samples were always taken at the end of the aeration step and before the settling phase. So sludge was always in an endogenous state.

Dissolved Organic Carbon (DOC) was analyzed during the experiments with a Sievers InnovOx Laboratory Total Organic Carbon Analyzer. All samples were filtered before they were analyzed using glass microfiber filters of 1.2µm.

Image analysis

Image characterization of the AS was performed with a Motic BA 310 microscope. Endogenous sludge, taken before the settling phase, was used. Images were taken with an EF-N Plan 10x0.25 ocular.

Offline batch respirometric experiments

To investigate the variation of the AS kinetics in function of time during all stages, offline batch respirometrie experiments were conducted. During the test, wastewater was fed to endogenous excess sludge of the SBRs in a VER of 30% to compare the substrate removal rate. During the test, filtered samples were taken in function of time to analyse the removal of DOC. As mentioned in Kovarova-Kovar and Egli (1998), it can be assumed that the concentrations of individual substrates in a complex mixture decrease linearly until the substrate is exhausted. Thus, the overall DOC removal rate will be the sum of the individual removal rates that are still present in the mixture. Those multicomponent DOC removal kinetics were described by the Eckenfelder equation (Eckenfelder et al. 2008):

$$\frac{S}{S_0} = e^{\frac{-K.X.t}{S_0}} \qquad (1)$$

where X is the biomass concentration (mgMLVSS.L^{-1}), t is time (d), K is a first order rate coefficient (d^{-1}). S_0 = start DOC substrate concentration at t_0 (mg.L^{-1}) and S = DOC substrate concentration at time t (mg.L^{-1}).

This equation describes in a simplified way the removal of substrate (expressed as DOC) in a multicomponent mixture. The above equation is experimentally proven by

Grau et al. (1975). K values were estimated via non-linear regression (equation 1) using GraphPad software.

Results and discussion

Reactor performance

The evolution of the MLVSS concentration in all reactors are shown in Figure 1. From the start of stage I to the end of batch 1 (day 1 - 39) the MLVSS was 2.76 ± 0.18 $gMLVSS.L^{-1}$. After switching to a new influent batch a decrease of MLVSS in all reactors was observed, which can be explained by the lower influent COD (Table 2). For the 3^{the} and 4^{the} batch, a stabilization in the MLVSS concentration was observed. For stage I, F/M ratio was 0.25 ± 0.05 $kgCOD.kgMLVSS^{-1}.d^{-1}$ (Figure 2).

During stage II, different OLRs were imposed in the reactors (Figure 2 B). 7 different influent batches were fed to the reactors (Table 2). Depending on the influent batch used, significant changes were observed in MLVSS concentrations. Higher sludge concentrations were observed in SBR 2 and 3 compared to SBR 1. This can be explained by the higher OLR in SBR 2 and 3. Changing the OLR influenced the F/M ratio significantly. At the beginning of stage II, F/M increased 2 and 3 times for SBR 2 and SBR 3 respectively, as a result of the increased OLR. Due to sludge growth in SBR 2 and 3, F/M decreased slowly. The average F/M during stage II was 0.32 ± 0.06 $kgCOD.kgMLVSS^{-1}.d^{-1}$, 0.38 ± 0.03 $kgCOD.kgMLVSS^{-1}.d^{-1}$ and 0.57 ± 0.04 $kgCOD.kgMLVSS^{-1}.d^{-1}$ for SBR 1, 2 and 3 respectively.

In period III, different VER were applied to SBR 2 and 3. During adaptation to the new VER, outspoken changes occurred in the MLVSS concentration. At the end of the feeding batch 11 (day 402), SBR 2 had a MLVSS concentration twice as high as SBR 3. During batch 2 and 3, the same trend was observed. The decrease of MLVSS in both reactors could be explained by the lower COD of the influent. As a result of this, different F/M ratios were observed. SBR 2 evolved at the end of stage III to a F/M ratio of 0.29 $kgCOD.kgMLVSS^{-1}.d^{-1}$ and SBR 3 to 0.66 $kgCOD.kgMLVSS^{-1}.d^{-1}$.

During all stages a good COD effluent quality was observed. An average COD of 62 ± 14 $mgO_2.L^{-1}$, 29 ± 10 $mgO_2.L^{-1}$ and 31 ± 11 $mgO_2.L^{-1}$ for stage I, II and III respectively. Although wide variation of OLR and VER were imposed to the reactors, a stable effluent quality was achieved which was well below Flemish discharge limits i.e. 125 $mgO_2.L^{-1}$.

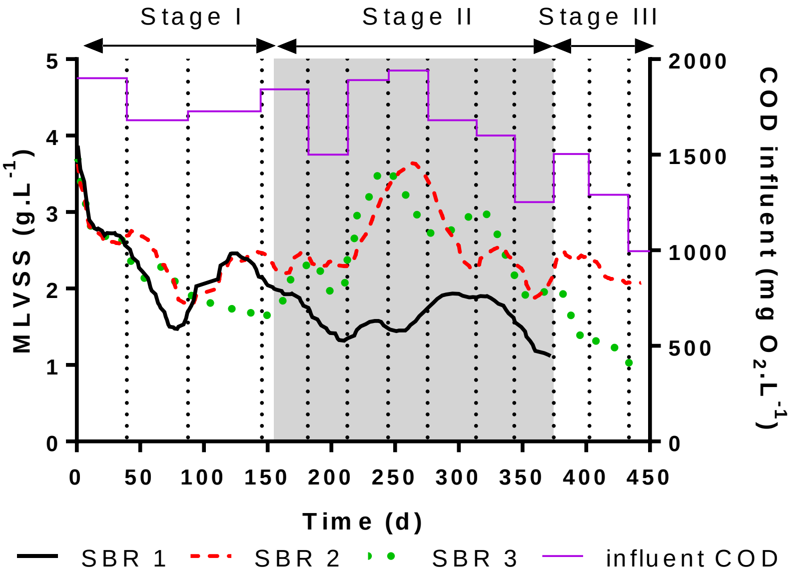


Figure 1: Evolution of the MLVSS in the three SBR systems and the influent COD, a dotted line represents a new feeding batch.

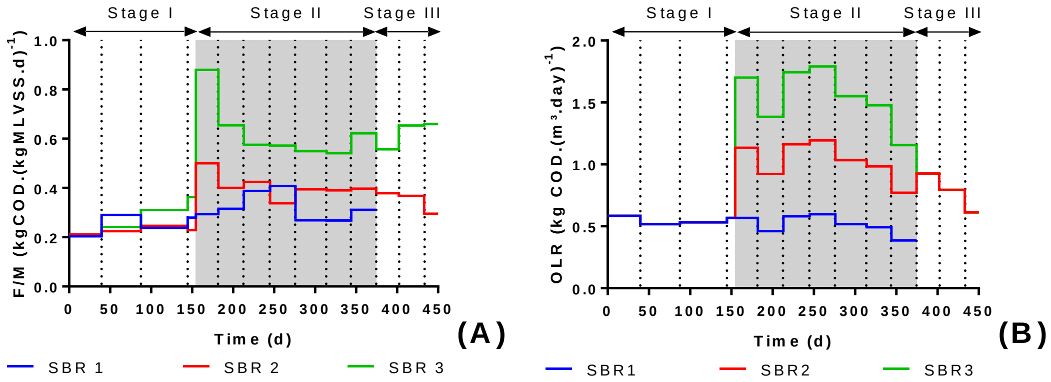


Figure 2: Evolution of (A) the average F/M and (B) the OLR for every influent batch in each SBR. A dotted line represents a new feeding batch.

Sludge activity

A respirogram showing the evolution of the specific OUR (sOUR)was constructed during each cycle to monitor the evolution of the sludge activity. A typical (Figure 3A) consisted of 4 distinctive sOUR levels, representing four different carbon removal rates. After the fourth level, the sludge reached the endogenous state. The average sOUR values for level 1, 2, 3 and 4 in Figure 3A are respectively 43.4, 13.1, 5.6 and 2.6 mg O_2.(gMLVSS.h)$^{-1}$. The endogenous respiration rate was 1.6 mg O_2.(gMLVSS.h)$^{-1}$. The corresponding DOC removal is expressed as S/S_0 in this figure.

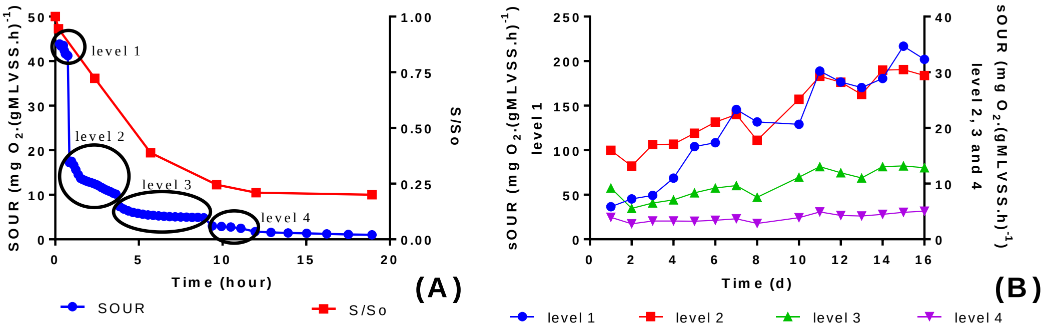


Figure 3: (A) Typical specific oxygen uptake rate profile for the chemical wastewater during a SBR cycle. 4 sOUR levels are identified. (B) Evolution of the average sOUR for the different rate levels during the first 16 batch feeding cycles for 1 SBR.

For every cycle an average sOUR value was calculated for each level defined in Figure 3A.
Figure 3B gives an overview of the evolution of these average sOUR values during the first 16 cycles. During adaptation of the continuous sludge to batch feeding, significant changes in the sOUR profile were observed. Most changes were observed during the first fifteen cycles, after which stabilization occurred (results not shown).
During the first 15 cycles, the sOUR for the most rapidly treatable components (level 1) increased 5 times (36 to 190 mg O_2.(gMLVSS.h)$^{-1}$). For the second (level 2), third (level 3) and fourth (level 4) sOUR level, sOUR increased 2 times. In combination with the higher activity, the time to reach the endogenous rate decreased by 43.9% from 13.1 h to 7.36 h. A similar trend was observed in all 3 SBRs.

Carbon removal kinetics

DOC removal kinetics were determined during the three different stages using equation 1. The seed sludge had a DOC removal rate coefficient K of 0.058 d^{-1} ± 0.003 d^{-1} (Figure 4). After 39 days, this value increased 17.5 times to 1.01 d^{-1}± 0.11 d^{-1}. The increased DOC removal rate corresponds to the significant increase observed in the sOUR levels (Figure 3B). As shown in this research and also mentioned before in literature by Grau et al. (1975) this equation can be used to describe the kinetics of a multicomponent substrate removal by a mixed culture. As shown in Figure 4, DOC kinetics doesn’t change anymore during stage II and III. As a conclusion it can be noticed that changing the OLR and VER, which leads to different F/M ratio’s, did not influence the removal kinetics for this wastewater.

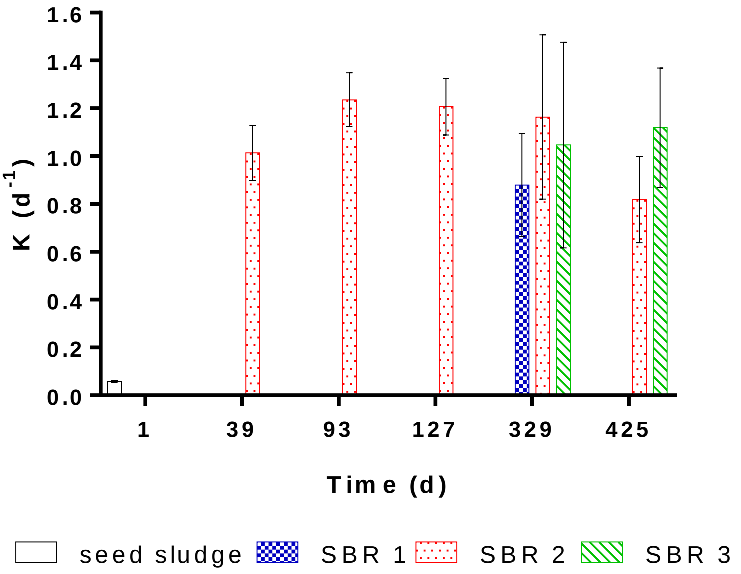


Figure 4: DOC removal kinetics for different influent batches in the 3 SBRs. Error bars represent the standard error.

Sludge settling

Increasing the substrate gradient in the system by decreasing the length of the feeding phase from continuous to pulse feeding had a strong positive impact on the sludge settleability. Figure 5 shows the evolution of the average SVI, after 30 minutes settling for the 3 SBRs. The most significant changes in the SVI evolution were found between day 8 and 17. The SVI_{30} gradually decreased in the three SBRs from 300 mL.gMLVSS^{-1} on day 1 to 85 mL.gMLVSS^{-1} on day 20. After day 20, the SVI_{30} improved gradually to a stable value of 40 mL.gMLVSS^{-1} at day 120. The SVI_{30}/SVI_5 ratio evolved slowly from day 20 to 100 to a value that remained stable between 0.85 and 0.95. The settling rate evolved from 0,02 m.h^{-1} to a rate between 10 and 13 m.h^{-1} in all SBRs corresponding to a good settling sludge (Martins et al. 2004).

Throughout stage I, good settling sludge was formed. Changing the OLR at the beginning of stage II had no influence on the SVI_{30}. During 220 operation days, SVI_{30} stayed almost equal in all three reactors with values between 25 and 45 mL.gMLVSS^{-1}. Changing the influent batch had no negative impact on the SVI_{30}, although between day 108 and 204 a less favourable SVI_{30}/SVI_5 ratio was obtained. Nevertheless, a settling rate between 9.5 and 13.8 m.h^{-1} was observed in all 3 reactors during the whole stage.

The SVI_{30} of the sludge in both reactors remained unchanged after changing the VER in stage III. SBR 2 and 3 had a low SVI with values between 45 and 25 mL.gMLVSS^{-1}. After cycle 400, the SVI_{30}/SVI_5 ratio became 1. A settling rate of 12 to 13.5 m.h^{-1} was measured in both SBRs.

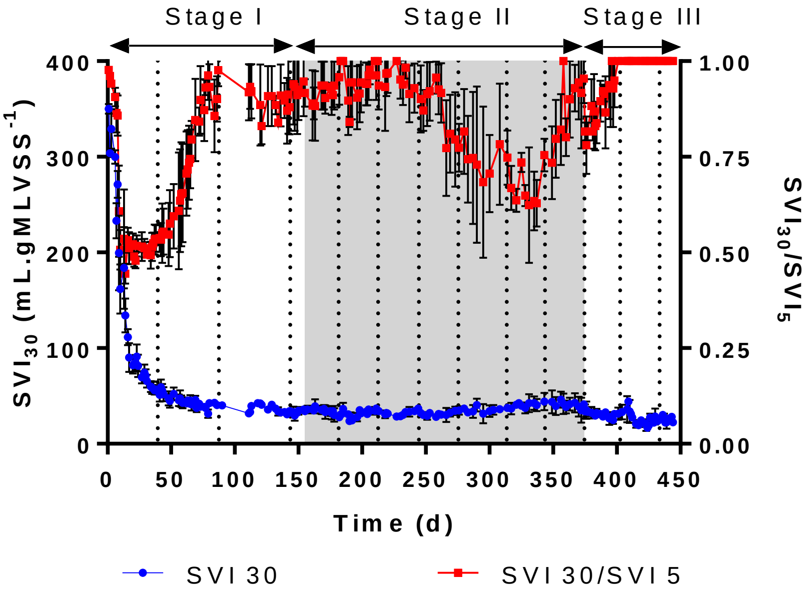


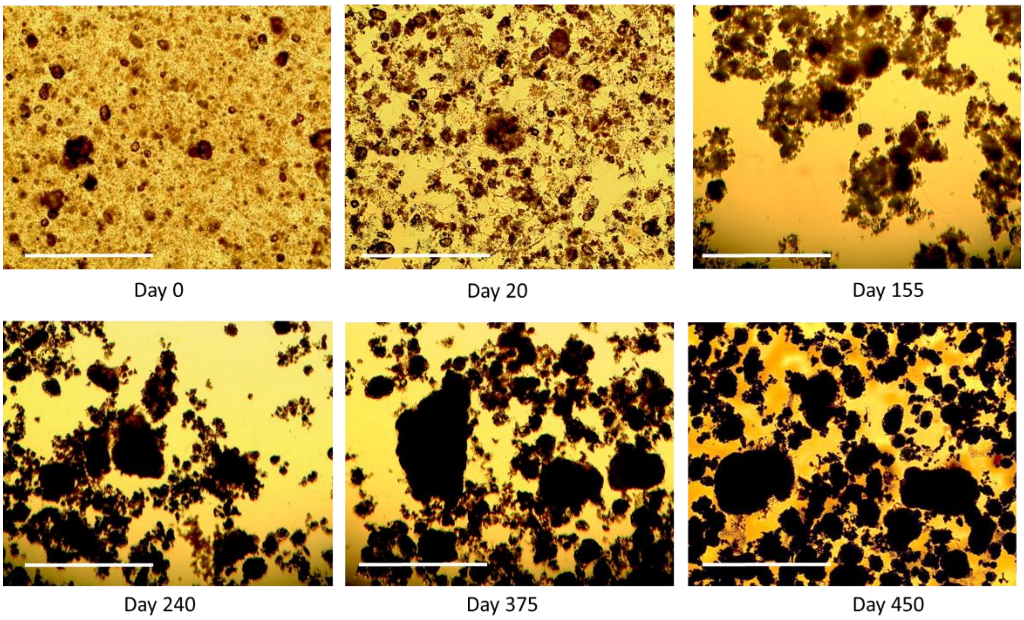
Figure 5: Evolution of the average SVI_{30} and SVI_{30}/SVI_5in the three SBR systems, a dotted line represents a new feeding batch. Error bars represent the standard deviation between the three SBRs.

Sludge morphology

Figure 6 illustrates the morphological changes of the sludge. The first picture in Figure 6 shows the seed sludge from the industrial WWTP. The sludge had a loose and irregular structure. After 10 days of SBR operation, more compact flocs appeared. After 20 days dark spots were formed. Between day 20 and 80, the formed flocs became larger and darker. After 80 days robust and stable flocs were formed. This morphological adaptation was observed in all three SBRs.

At the beginning of stage II, flocs with a diameter of 100µm were observed in the sludge. During the transition to a new OLR, flocs became bigger in all reactors. At the end of stage II, al reactors had a good settleable sludge (Figure 5). This corresponds to the well-defined sludge flocs that were observed during the microscopic investigation.

During stage III, the microscopic structure of the sludge in SBR 2 and 3 underwent no significant changes, which is in correlation to the sludge settling characteristics. Well-shaped flocs were preserved. In accordance to granular sludge, granule size has to be at least 0.2mm (de Kreuk et al. 2007). Although the floc size of the granules was not measured it can be observed that a substantial amount of the flocs had a size bigger than 0.2mm.



Day 0
Day 20
Day 155
Day 240
Day 375
Day 450

Figure 6: Evolution of the sludge morphology (40x magnified) during the whole experiment. The white scale bar represent a length of 500µm.

Discussion

In this study the effect of a changing feeding pattern, from continuous to batch/pulse, on the characteristics of AS was studied. Van den Broeck (2009) mentioned a significantly different transition period for different sludge characteristics (SVI, sOUR, microscopic structure) which was also confirmed in this study. Changing the feeding pattern resulted in rapid and significant improvement of the microbial kinetics expressed as sOUR. The adaptation time corresponded to half a sludge age. This is significantly faster than reported in Van den Broeck et al. (2009) who showed an adaptation of approximately 20 days for the sOUR with a sludge age of 20 days after changing the feeding pattern and influent composition of domestic AS. Earlier research from Chudoba et al. (1973, 1985), Martins et al. (2003), Van den Eynde et al. (1983) and Verachtert et al. (1980) using synthetic wastewater and Van den Eynde et al (1982) using industrial wastewater already stressed the importance of the feeding pattern for the settling characteristics of the sludge which is also confirmed in this study with a real petrochemical industrial chemical wastewater.

A stable and robust AS system was formed during the first adaptation period. Changing the VER, OLR and influent composition had no significant influence on the settleability of the sludge. During the whole period, SVI values between 25 and 45 $mL.gMLVSS^{-1}$ were achieved. Carbon removal rate kinetics showed no significant difference between the reactors, but there was a significant improvement during adaptation. In accordance to the F/M ratio, a higher ratio was obtained with the highest VER of 60% and F/M ratios 2 to 3 times higher than in the industrial installation. The bad settling sludge was turned over into a good settling sludge in 20 days which was also achieved in Martins et al. (2004) Martins showed an adaptation time of 7 days for the SVI after changing the feeding pattern from continuous to pulse feeding with a SRT of 10 days. This is 0.7 times the sludge age which is almost the same as for this wastewater with a value of 0.67. Since the industrial company struggles with bad settling sludge (Figure 5), changing the feeding pattern could mean a beneficial improvement for the settling. The obtained settling properties in the present study correlated to the characteristics of granular sludge. As defined in de Kreuk et al. (2007), granular sludge has a settling rate higher than 10m.h^{-1} and a SVI_{30}/SVI_5 equal to 1 which is also obtained in this study. The observed effects can, to a large extent, be explained by the kinetic selection theory of Chudoba et al. (1973, 1985), who have shown that the activity of microorganisms depends on substrate composition and concentration. This implies that (among many other factors) the feeding pattern in the reactor exerts an important influence on microbial dynamics in the AS.

Growing interest last years is observed for the SBR technology to treat wastewater since some important benefits can be addressed to the SBR (Mace and Mata-Alvarez 2002): (i) lower cost than conventional biological treatment methods (ii) lower footprint (iii) flexible for wide swings in hydraulic and organic loadings (iv) easier to control filaments and settling problems and (v) dynamic process control.
Nevertheless, the number of SBR reactors is still low in industry, especially in the (petro)chemical industry. In the authors opinion, a lack of information is still present in literature about SBR treatment of this type of wastewater. Mostly fear for sludge inhibition is referred to as a reason to choose for other systems than SBR (USEPA 2000). Interestingly, different researchers stated the benefits of the SBRs, compared to the CAS system, to remove difficult degradable (toxic) components. For example, Papadimitrou (Papadimitriou et al., 2009) compared the adaptation of activated sludge for wastewater that contained phenol and cyanide. They clearly showed the superior removal capacity of the SBR system to remove both pollutants. Furthermore, the authors showed better performance to shock loading of these chemicals in the SBR and inactivation and disintegration of the sludge with phenol concentrations above 800 mg.L^{-1} was seen in the CAS system. In addition, the study clearly showed better settling properties in the SBR. Moreno and Buitrón (2012) (Moreno-Andrade and Buitrón, 2012) investigated the degradation of 4-methylaniline in a SBR. They demonstrated the ability of AS to adapt to this difficult degradable chemical. In (Moreno-Andrade and Buitrón, 2004) the capability of the SBR is presented to degrade 4-chlorophenol. In the present study it is shown that inhibition of activated sludge was not relevant for the petrochemical wastewater used. The activated sludge showed a good performance even when subjected to triplication of the OLR and doubling of the VER.

To conclude, the researchers have demonstrated that activated sludge from a CAS system could quick and easily adapt to pulse fed activated sludge in a SBR reactor. Furthermore, activated sludge characteristics evolved positively. In this research, lab scale SBR results were compared with the full scale results. Future work has to be done to compare the lab scale SBR results with a lab scale CAS system to exclude effects like different degrees of mixing in the full scale plant, substrate gradients in the perfectly mixed processes, differences in pH or nutrients addition and variable influent composition of the wastewater or different organic load rate or oxygen concentration in the reactor.

Conclusions

The results of the experiments allow the authors to conclude that batch feeding, significantly influenced the characteristics of the microbial population of the AS in a positive way. In SBR systems more advantageous treatment rates and improved settling characteristics can be achieved in comparison to continuous flow systems with the chemical wastewater. As a result of this higher activity due to changing the feeding pattern, the industrial treatment plant could be built more compact and higher wastewater flows could be treated.

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