Industrial and municipal wastewater treatment in the sequencing batch reactor

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A mixture of Industrial wastewater from chemical industry (varnish, paint and pigments production) and municipal wastewater was treated in pilot sequencing batch reactor (SBR). Results of the pilot experiments show that the foaming problem has great influence on the behavior of SBR, especially when the ratio between industrial and municipal wastewater is very high.

Foaming problem was negligible when the mixture with φ = 20 % of the industrial wastewater and φ = 80 % of the municipal wastewater was treated.

With the operational cycle of 6 h with anoxic (non-aerated) and aerobic (aerated) phase the required effluent quality was obtained according to regulations for treated wastewater that flows into the recipient. Operational cycle (aerobic phase) can be 60 min shorter at minimal organic and nitrogen loading.

Key words: *Biological wastewater treatment, chemical industry wastewater, industrial wastewaters, sequencing batch reactor (SBR)*

Introduction

Sequencing batch reactor is the system with activated sludge[1] that operates on the *fill-and-draw* basis. In recent years, the modification of the *fill-and-draw* process is intensifying as a sequencing batch reactor (SBR) system. SBR system offers various advantages in comparison with conventional activated sludge systems-compact system, very flexible, could be fully automated. All wastewater treatment plants that were in operation between 1914 and 1920 were designed as fill-and-draw systems. When continuous flow activated sludge systems were developed, the interest for sequencing batch reactors extremely declined. In the early 1960's, SBR systems began to reappear with the development of new technology and equipment.[2–8]

The process of SBR is a procedure composed by one reactor or by a series of parallel reactors where the complete treatment procedure is carried out; wastewater treatment and separation of sludge from treated wastewater. The operating principles of the SBR are characterized by five discrete periods: fill, react, settle, decant and idle. When the SBR is subjected to sequential redox environments (anaerobic/anoxic/aerobic conditions) during the react period first two steps, it provides the removal of organic substrate and nutrients simultaneously. Ammonium is oxidized to nitrite and nitrate (nitrification) in the aerobic phase and nitrate is reduced to N_2 (denitrification) in the anoxic phase of the react period. The organic substrate from the wastewater is oxidized in the anoxic phase in the denitrification process.

Although the process in SBR resembles the classical *fill-and-draw* process with activated sludge, the development of SBR is most recent.[9–11] The purpose of recent research was to stress advantages of SBR in comparison to conventional flow systems. The principal investigations are publications of *Dennis* and *Ervine,*[2,5,6,9] in which they studied the effects of *fill/react* ratios. *Hopker* and *Schroeder*[3] found that smaller loading gives better quality of effluent. *Ketchum* and *Liao*[6] studied the possibilities of SBR for tertiary treatment, especially for phosphorus removal. *Irvine* et al.[5] presented the possibilities of nitrification and denitrification at the given plan and control of the process.

The majority of advantages of the SBR may be attributed to the flexible nature of operating quantities.[11–19] A large choice of system quantities can be the consequence of constant volume, where we can change *fill/react* ratios and the time of aeration. Flexibility of operating parameters also enables the understanding of basic mechanisms of the process, and critical phases that are very important for further application.[1,21–24] Recently, a unified basis of design for SBRs was prepared mainly covering practical aspects of SBR technology and emphasizing the need for appropriate design guidelines.[25]

The purpose of this study was to investigate the treatment of the mixture of the industrial and domestic wastewater in the SBR and to determine the key quantities affecting the behavior of this experimental reaction system.

Materials and methods

Wastewater characteristics

The wastewater treated in the SBR was a mixture of industrial wastewater and municipal wastewater from the nearest village. The industrial wastewater was physico-chemically pre-treated wastewater from the factory that produces interior wall paints, decorative wall coatings, concrete and tinting paints. The pre-treated wastewater had COD from γ = 800 to 1800 mg L^{-1} with specific organic pollutants (paint additives) that could cause problems at biological treatment.

So far, the maximum ratio of industrial wastewater: municipal wastewater was calculated as ψ = 1:4; the calculation was based on the estimated municipal wastewater collection system costs. This ratio could change in the case of production enlargement.

According to regulations for treated wastewater (SBR effluent) that flows into the recipient the limited values for the determined quantities that have to be reached were as follows: COD $\gamma < 120$ mg L^{-1}, BOD_5 $\gamma < 25$ mg L^{-1}, NH_4–N $\gamma < 10$ mg L^{-1}, NO_2–N $\gamma < 1{,}0$ mg L^{-1}, NO_3–N is dependant on receiving water flow but it have not exceed γ = 30 mg L^{-1}.[26]

Pilot sequencing batch reactor (SBR)

The experiments were carried out in 70 L laboratory pilot plant SBRs. The reactor was equipped with a stirrer, air supply system, and measuring tool for ORP (redox potential), DO (dissolved oxygen) and pH. The activated sludge was originated from the nearest wastewater treatment plant adapted to treated wastewater for 3 weeks or more when all effluent quantities were constant. The mass concentration of the mixed liquor suspended solids in the SBR (activated sludge) was between γ = 3.5 and 4.8 g L^{-1}. The treatment process in the SBR was computer controlled.

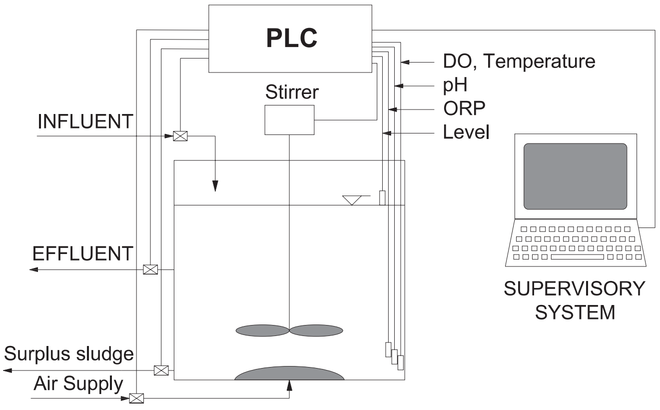

Fig. 1 – *Scheme of the automated laboratory pilot plant SBR*

Slika 1 – *Shema automatiziranog laboratorijskog pilot-postrojenja SBR*

All measurements and analyses were carried out with regard to Standard Methods.[27]

Experiments

Fixed time-pattern pilot SBR experiments with two central phases (anoxic and aerobic) were carried out. The activated sludge (from the nearest wastewater treatment plant) was adapted to treated wastewater for three weeks or more when all effluent parameters were constant.

Dissolved oxygen, pH, and redox potential (ORP) were measured *on-line* in all experiments. Once a week pollution quantities measurements were carried out during one cycle (COD, and N compounds).

After the activated sludge adaptation period, the pilot experiments started with a mixture of φ = 40 % of industrial wastewater and φ = 60 % of municipal wastewater (Experiment 1). Wastewater characteristics are presented in Table 1.

All experiments were carried out at the temperature of 20 °C. pH value varied between 7.5 and 8.1.

Table 1 – *Wastewater characteristics and results of the treatment quantities for experiments 1–3*

Tablica 1 – *Karakteristike otpadnih vodâ i rezultati i veličine dobivene obradom za eksperimente 1–3*

Quantity	Experiment 1*		Experiment 2**		Experiment 3***	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
COD, γ/mg L^{-1}	680	215	516	48	438	56
BOD_5, γ/mg L^{-1}	335	-	310	2	247	4
TKN, γ/mg L^{-1}	87.4	-	69.5	4.7	56.5	6.4
NH_4–N, mg L^{-1}	40.7	-	33.3	1.5	28.6	2.6
NO_2–N, γ/mg L^{-1}	0.3	-	0.3	0.15	0.3	0.3
NO_3–N, γ/mg L^{-1}	2.5	-	1.2	14.8	1.4	9.0
N-total, γ/mg L^{-1}	90.2	-	71	16.45	58.2	15.7
ζ= (COD/TKN)	9.6	-	7.4	10.2	7.8	8.8

* 40 % industrial wastewater + 60 % municipal wastewater;
$r_{F/M}$ = 0.08 g $g^{-1}d^{-1}$
40 % industrijske otpadne vode + 60 % komunalne otpadne vode;
$r_{F/M}$ = 0,08 g $g^{-1}d^{-1}$

** 20 % industrial wastewater + 80 % municipal wastewater;
$r_{F/M}$ = 0.06 g $g^{-1}d^{-1}$
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Artan and *Orhon*[25] proposed a unified procedure for SBR systems operated for nitrogen removal. Nitrogen removal performance depends upon the balance between three key quantities, namely the nitrification capacity, the denitrification potential and the available nitrate. Biological nitrogen removal proceeds as a sequence of two different processes: firstly nitrification which oxidizes ammonia to nitrite (NO_2^-) and nitrate (NO_3^-) and then denitrification which reduces nitrate and returns it to the atmosphere as molecular nitrogen (N_2). Most biodegradable COD is consumed in the denitrification process. These two processes are usually realized in alternating aerobic and anoxic periods.

The procedure for nitrogen removal by pre-denitrification was implemented for the wastewater with characteristics specified in Table 1 (Experiment 1); kinetic and stoichiometric coefficients from literature were used in calculations (24). The duration of the phases for the experiments is presented in Table 2. The SBR liquid exchange ratio was $\varphi = 10$ %.

Liquid exchange ratio is volume of water added into SBR in the cycle/total volume of the SBR. For example: 5 L/50 L = 0.1 or $\varphi = 10$ %.

Table 2 – *Phase duration during one cycle in the SBR*

Tablica 2 – *Trajanje faze jednog ciklusa u SBR*

Phase Faza	Experiment 1 Eksperiment 1	Experiment 2 Eksperiment 2	Experiment 3 Eksperiment 3
anoxic phase*, *t*/min anoksična faza, *t*/min	60	60	60
aerobic phase, *t*/min aerobna faza, *t*/min	190	250	190
settling, *t*/min taloženje, *t*/min	30	30	30
withdrawing, *t*/min pražnjenje, *t*/min	10	10	10
idling, *t*/min prazan hod, *t*/min	10	10	10
total, *t*/min ukupno, *t*/min	300	360	300

* Filling phase (15 minutes) was running during the anoxic phase

* Faza punjenja (15 minuta) provodila se za vrijeme anoksične faze

In Experiment 1, the system collapsed already during the adaptation period due to the foaming problems. In this case, the SBR cycle procedure was not reliable; specific properties of the industrial wastewater could not be adequately expressed with kinetic quantities and stoichiometric coefficients.

The foaming effect caused by the additives in the industrial wastewater was studied experimentally; mixture of industrial and municipal wastewater with $\varphi = 30$ and $\varphi = 20$ % of the industrial wastewater was aerated in the SBR pilot reactor. Visual observations showed that the foaming effect was negligible when the mixture with $\varphi = 20$ % of the industrial wastewater was aerated.

Mixture with $\varphi = 20$ % of the industrial wastewater and $\varphi = 80$ % of municipal wastewater was treated in the pilot SBR in Experiment 2. Characteristics of the mixture are presented in Table 1. In Experiment 2, the mixture with the highest organic and nitrogen loading was used.

The addition of the wastewater into the SBR was increased to $\varphi = 20$ % and the duration of the aerobic phase was increased to $t = 250$ min (Table 2).

The next Figure (Fig. 2) shows changes of ORP and dissolved oxygen (DO) during one cycle in the SBR for Experiment 2.

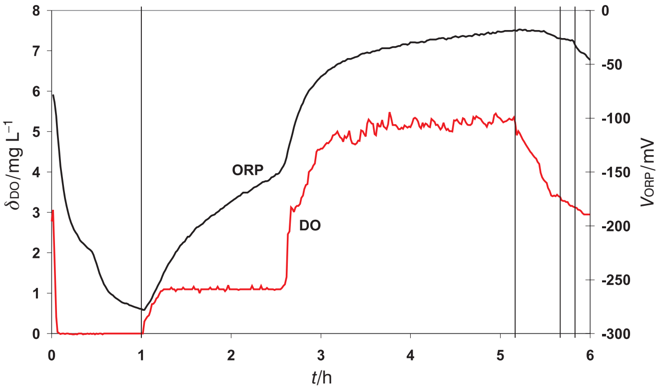

Fig. 2 – *Time course of ORP and dissolved oxygen (DO) for Experiment 2*

Slika 2 – *Vremenska promjena redoks potencijala (ORP) i otopljenog kisika (DO) u eksperimentu 2*

Fig. 3 shows the COD and N mass compounds concentration profile during the cycle. Nitrate was completely removed during the anoxic phase and nitrite during the aerobic phase; nitrification was completed during the aerobic phase. All quantities in the SBR effluent were below limit values.

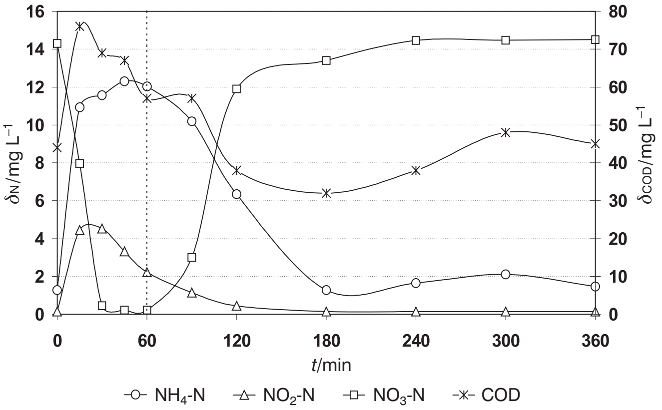

Fig. 3 – *Time course of COD and nitrogen compounds changes for Experiment 2*

Slika 3 – *Vremenska promjena kemijske potrošnje kisika (COD) i dušikovih spojeva u eksperimentu 2*

In Experiment 3, the mixture ($\varphi = 20$ % industrial wastewater + $\varphi = 80$ % municipal wastewater) with the lowest organic and nitrogen loading was used. Experiment 3 was designed with the use of the experimentally verified data from Experiment 2. It revealed that, for the required SBR effluent quality, the aerobic phase can be 60 min shorter (Table 2).

Fig. 4 shows changes of ORP and dissolved oxygen (DO) during one cycle in the SBR for Experiment 3.

Fig. 5 shows the COD and N compounds mass concentration profile during the cycle in Experiment 3. Nitrate and ni-

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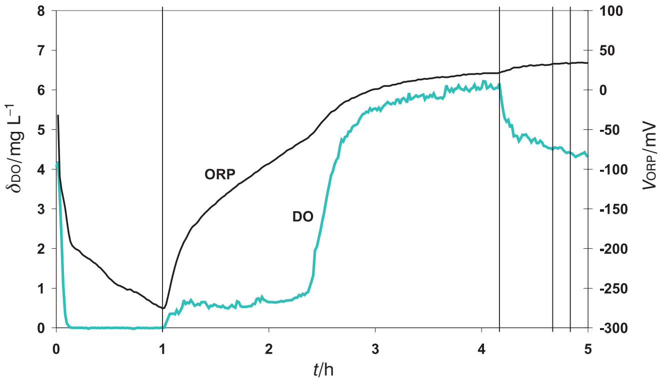
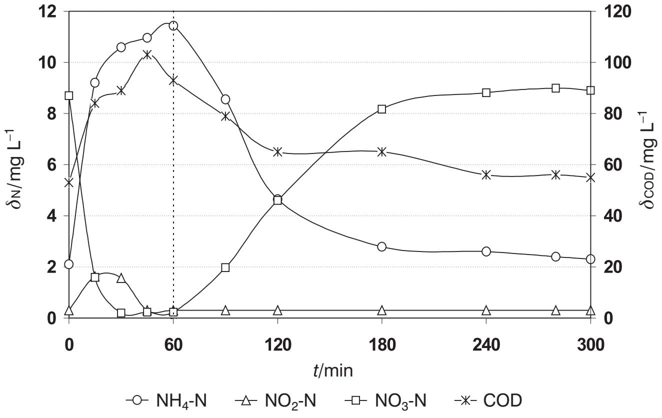
[*] Liquid exchange ratio is volume of water added into SBR in the cycle/total volume of the SBR. For example: 5 L/50 L = 0.1 or $\gamma = 10$ %.

trite were completely removed during the anoxic phase; nitrification was completed during the aerobic phase. All quantities in the SBR effluent were below limit values.



F i g. 4 – *Time course of ORP and dissolved oxygen (DO) for Experiment 3*

S l i k a 4 – *Vremenska promjena redoks potencijala (ORP) i otopljenog kisika (DO) u eksperimentu 3*



F i g. 5 – *Time course of COD and nitrogen compounds changes for Experiment 3*

S l i k a 5 – *Vremenska promjena kemijske potrošnje kisika (COD) i dušikovih spojeva u eksperimentu 3*

Conclusions

The applicability of the sequencing batch reactor (SBR) for industrial/municipal wastewater treatment was investigated carrying out experimental tests. The several series of experiments were carried out at different operating conditions, using the mixture with different proportions of industrial and municipal wastewater at the entrance to the reactor. The main objective of the study was to define the optimal ratio between industrial and municipal wastewater for the required effluent quality.

The high average removal efficiencies of NH_4–N, NO_2–N, NO_3–N and COD were obtained. The duration of the appropriate phases for the treatment of wastewater with the highest and lowest organic and nitrogen loading was presented. Results of the pilot experiments revealed the foaming as the main problem affecting the behavior of SBR. The foaming problem was negligible when the mixture with φ = 20 % of the industrial wastewater and φ = 80 % of the municipal wastewater was treated in the SBR.

It can be concluded that a detailed description of the sequencing batch reactor (SBR) should be based only on comprehensive experimental work.

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List of abbreviations and symbols
Popis kratica i simbola

BOD$_5$	– biochemical oxygen demand in 5 days, mgL^{-1} – biokemijska potrošnja kisika za 5 dana, mg L^{-1}
COD	– chemical oxygen demand, mg L^{-1} – kemijska potrošnja kisika, mg L^{-1}
DO	– dissolved oxygen concentration, mg L^{-1} – koncentracija otopljenog kisika, mg L^{-1}
F/M	– food/microorganisms Loading (g BOD$_5$/g$_{VSS}$.d) – sadržaj hrane/mikroorganizama
NH$_4$–N	– ammonium nitrogen, mg L^{-1} – amonijski dušik, mg L^{-1}
NO$_2$–N	– nitrite nitrogen, mg L^{-1} – nitritni dušik, mg L^{-1}
NO$_3$–N	– nitrate nitrogen, mg L^{-1} – nitratni dušik, mg L^{-1}
N-total	– total nitrogen (TKN+N–NO$_2$+N–NO$_3$); mg L^{-1} – ukupni dušik (TKN+N–NO$_2$+N–NO$_3$); mg L^{-1}
ORP	– oxidation reduction potential or redox potential,mV – oksidacijsko-redukcijski potencijal ili redoks-potencijal, mV
SBR	– sequencing batch reactor – slijedni šaržni reaktor
TKN	– total Kljedahl nitrogen (bounded N + ammonium N); mg L^{-1} – ukupni dušik po Kjedahlu (vezani N + amonijski N); mg L^{-1}
m	– mass, mg, g – masa, mg, g
t	– time, min, h, d – vrijeme, min, h, d
V	– volume, L – volumen, L
γ	– mass concentration, mg L^{-1}, g L^{-1} – masena koncentracija, mg L^{-1}, g L^{-1}
θ	– temperature, °C – temperatura, °C
φ	– volume fraction, % – volumni udjel, %
ψ	– volume ratio – volumni omjer
r	– mass loading rate, (m$_{food}$ m$^{-1}{}_{microorg,}$ t^{-1}, g g^{-1}d^{-1}) – masena brzina punjenja
$r_{F/M}$	– m_{BOD5} ($m^{-1}{}_{VSS}$ t^{-1}, g g^{-1} d^{-1})

SAŽETAK

Obrada industrijskih i komunalnih otpadnih voda u slijednom šaržnom reaktoru

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Smjesa industrijskih otpadnih vodâ (proizvodnja lakova, boja i pigmenata) i komunalnih otpadnih voda obrađivana je u pilotnom slijednom šaržnom reaktoru (SBR). Rezultati eksperimenata pokazuju da pjenjenje značajno utječe na rad SBR-a, posebice u uvjetima velikih omjera industrijskih i komunalnih otpadnih voda na ulazu u reaktor.

Problem pjenjenja je beznačajan kada se obrađuje mješavina φ = 20 % industrijskih otpadnih voda i φ = 80 % komunalnih otpadnih voda.

S operacijskim ciklusom od 6 sati s anoksičnom (faza bez aeriranja) i aerobnom (aeriranom) fazom postiže se željena kvaliteta efluenta za obrađenu otpadnu vodu koja odlazi u recipijent. Operacijski ciklus (aerobna faza) može biti i 60 min kraća ako je sadržaj organskih tvari i dušika pri punjenju reaktora minimalan.

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