Dedicated to Prof. Gheorghiţa Jinescu
on the occassion of her birthday

Intensive Biological Process Based on SBR Reactor for Industrial Wastewater Treatment

MARGARETA NICOLAU*, VIOREL PATROESCU, CRISTIANA COSMA, LAURENTIU DINU, COSTEL BUMBAC, LUCIAN CONSTANTIN
National Research and Development Institute for Industrial Ecology ECOIND, 90-92 Panduri Str., 050663, Bucharest, Romania,

A two-stage aerobic Sequencing Batch Reactor system (SBR) designed and constructed by INCD-ECOIND's specialists was used for treatment of the wastewater discharged from drugs fabrication (conditioning operations), with variable concentrations of organic load: COD = 1200-3300 mg O_2/L, BOD_5 = 490-1570 mg O_2/L. After acclimation period, the 1st stage and 2nd stage SBRs were able to achieve COD and BOD removal, with global efficiencies ranging from 63-97% and 82-99% respectively (HRT = 9 h). The effluent quality is in compliance with the discharge standards (GD352/05 - NTPA002). The paper also presents laboratory-scale experimentation carried out for the processing of excess biological sludge (stabilization/conditioning, leaching tests) in order to find out its subsequent destination.

Keywords: COD, BOD removal, two stage SBRs, industrial wastewater, drugs

The biological removal of organic matter and nutrients from municipal and industrial wastewater can be achieved using various process configurations. One of the system that has been demonstrated to have a good potential in biological process is Sequencing Batch Reactor (SBR), which offers many advantages compared with a conventional activated sludge system: minimal space requirements, easiness of management and possibility of modification during trial phases through on-line control of treatment strategy [1].

SBR system is consisting from a single tank operating on a cycle Aeration - Settling - Draining - Feeding, the process flow being intermittent [2,3].

The reactor geometry is a very important parameter for the efficiency level due to fact that SBR involves internal separation of fluids. Different reactor shapes generates selective pressures on microbial components of biomass which is influencing the carrier-biomass contact level and subsequently the mass transfer flow.

The SBR technology is applied in 138 domestic sewage plant and 51 plants for industrial wastewater treatment in Germany. The system selection can be based on economic criteria. The plants are generating effluents comparable to those of continuous flow plants [4,5].

The SBR is particularly adequate for highly variable hydraulic and organic loads due to its ability to modify process parameters without any physical modifications on the reactor [6].

SBRs have been increasingly used for the treatment of highly concentrated wastewater (COD: g/L - tens g/L), such as:

- piggery wastewater with COD, nitrogen and phosphorus removal efficiencies above 98% [7];
- wastewater from cheese production with average purification level of 97.7% for total COD and 99.8% for BOD_5 [8,9];
- effluents from goats farms and cheese fabrication with COD removal above 99% [10];
- tannery wastewater, using SBR with biomass supporting material and separate ozonation step in order to enhance the biodegradability of recalcitrant components. A fraction of the working volume was drawn, (intermediate drawing) ozonated, recycled to SBR (intermediate feeding) and treated by aerobic oxidation (2nd cycle) before the final drawing. High efficiencies were registered for the removal of COD, 97% and ammonia, 98% [11];
- wastewater from oil refinery in two stage SBR (HRT_1 = 9.6 h, HRT_2 = 16 h). The global efficiencies achieved COD removal of 95.3% and extractable products of 99.8% being higher than the anaerobic process and fixed bed reactor [6].

However, it is often reported that SBR is associated with high sludge volume index (> 200 $mL.g^{-1}$). A good balance between filamentous bacteria (responsible for this aspect) and flocs-forming bacteria is fundamental for an efficient plant operation [6].

This work is presenting the results of laboratory pilot scale experiments performed on two stages SBRs, for drugs wastewater treatment in order to achieve the discharge limits imposed by Romanian legislation (GD352/05-NTPA002). The paper is also presenting laboratory-scale experimentation carried out for processing of excess biological sludge (stabilization/conditioning, leaching tests) in order to find out its subsequent destination.

Experimental part

Sequencing Batch Reactors Operations

The sequential biological reactor pilot installation (see fig.1) used for the treatment experiments on wastewater generated by drugs fabrication (water resulted from conditioning processes) was designed and built by the technological engineering group of INCD-ECOIND.

The installation's construction scheme is presented in figure 2.

SBR is including five distinct cycles: feeding, reaction, settling, discharge, stand by.

The installation inflow, stored in vessel V1, is pumped using peristaltic pump P1 in the sequential bio-reactor SBR1. After the achievement of imposed level, the P1 pump is automatically stopped by the PLC programmable automat, which opens the electro vane in order to start

* email: tehnologi@incdecoind.ro; ecoind@incdecoind.ro

Fig. 1. Sequential bioreactors pilot laboratory installation

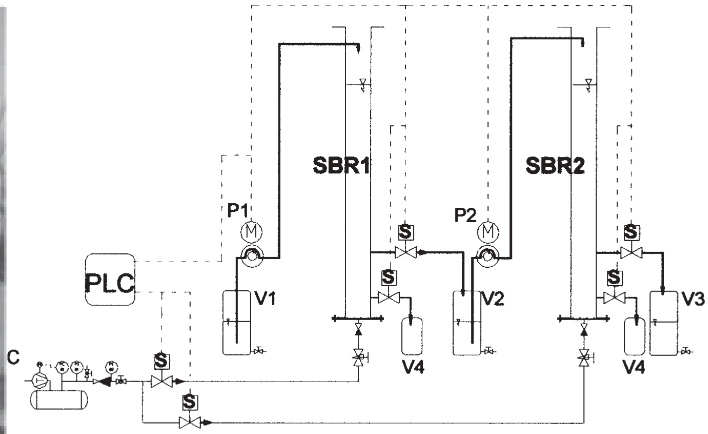

Fig. 2. The technological scheme of pilot laboratory installation used for the treatment of wastewater resulted from drugs fabrication

the SBR 1 aeration. At the end of aeration period, the PLC automatically closes the aeration electro vane, making possible to start the settling period. After settling, the programmable automat is opening the discharge vane of 1st stage treated effluent, to the V2 storage vessel. When the effluent discharge is complete, the PLC is opening the electro vane for the evacuation of in excess sludge to the V4 storage vessel and is closing the effluent discharge vane. When the evacuation of in excess sludge is finalised, the electro vane for the evacuation of in excess sludge is closed automatically, and because it is the end of the cycle for the SBR1, the feeding pump P1 is started for a new cycle.

The SBR1 sequential bio-reactor effluent is treated in a similar way in the 2nd stage of biological treatment (SBR2).

The operating parameters for the two stages are presented in table 1.

Wastewater composition

The wastewater flows discharged from drugs conditioning processes (oral solid preparations and injections) are formed from water resulted from cleaning of equipment, floors and spent solutions from regeneration of demineralisation installation ion exchangers.

The wastewater presented a high organic load COD = 1160-3300 mg O_2/L and BOD_5 = 489-1570 mg O_2/L, with a biodegradable potential (Symons ratio = 0.4-0.5).

The variation range of the indicators analysed in order to assess the quality of installation inflows are presented in table 2.

Reactors set up

Inoculation of SBR reactors was made using biological sludge resulted from the recirculation system of Pitesti city wastewater treatment plant. The sludge was adapted in a two weeks period to the wastewater resulted from drugs fabrication, using a continuous feeding flow installation.

Table 1
TECHNICAL DATA OF SBRs

Data	SBR_1 stage	SBR_2 stage
Vessel's operating capacity	7.5 l	5 l
Clarified treated water allocated volume	5 l	3 l
Feeding time	15 min.	15 min.
Reaction time	9 h	9 h
Settling time	2.5 h	2.5 h
Clarified treated water evacuation time	10 min.	10 min.
Sludge evacuation time	5 min	5 min
Sludge concentration	2-6.5 g s.d.s./l	2-4 g s.d.s./l
Dissolved oxygen	2.5-4.5 mg/l	2.5-4.5 mg/l

*s.d.s. = sludge dry substance

Table 2
WASTEWATER CHARACTERISATION DATA VS.

No.	Quality indicator	Variation range	Imposed limits in accordance with GD352/05-NTPA002	Method
1	pH	5.72-6.77	6.5-8.5	SR ISO 10523-97
2	TSS, mg/L	36-83	350	STAS 6953-81
3	COD, mgO_2/L	1166-3322	500	SR ISO 6060-96
4	BOD_5, mgO_2/L	489-1572	300	SR EN 1899/2-02
5	BOD_5/COD	0.4-0.5	-	-
6	$N\text{-}NH_4^+$, mg/L	<0.01-0.89	30	SR ISO 14911-06
7	N_t, mg/L	0.75-2.29	-	SR ISO 10048-01
8	P_t, mg/L	1.32-6.58	5	SR EN ISO 6878-05
9	Extractable substances, mg/L	<10-14.4	30	SR 7587-96
10	Non-ionic detergents, mg/L	11.75-20	25	Company standard
11	Anionic detergents, mg/L	<0.05		SR EN 903-03

A pH correction at value about 7, using 1N NaOH solution, was needed for the feeding water. The inflow samples were enriched with nutrients, by adding an urea and mono-potassium phosphate nutritive solution, in order to assure a ratio of 100 BOD_5 : 5 N : 1 P, needed for the growing of bacteria biomass.

An anti-foaming agent was added to the feeding water in order to prevent the foaming phenomenon.

Investigation methods

The experiment was monitored via inflow analysis (each time when feeding was changed) and of 1st and 2nd stage treated effluents (average daily samples), for the following parameters: pH, COD, BOD_5, TSS, Non-ionic detergents, total P, total N.

The analytical tests were performed in accordance with the enforced Romanian standards, which are complying with European legislation.

A simple and rapid technique was used for the microscope analyse of activated sludge, consisting of observation of biological sludge using optical microscope, on slide and live sample.

The notification of functional activity of activated sludge biocenosys was performed in accordance with Godeanu – Catana method.

Sludge processing

The in excess biological sludge was stabilised in aerobic conditions (τ aeration = 15 days), conditionaed in two variants (variant I -lime, variant II – strong cationic poly-electrolyte) and dewatered via centrifugation.

The physico-chemical characterisation of the processed biologic sludge has taken into consideration the determination of DOC (dissolved organic carbon) and LOI (loss on ignition).

Leaching tests in accordance with the prescriptions of Order 95/2005 (regarding the set up of acceptance criteria and preliminary acceptance procedures for storage of waste and national list of accepted waste in each class of waste storage) were performed in order to establish the storage type in which the excess sludge can be accepted.

Results and Discussions

Operation of treatment process

The analytical investigations performed during the whole operating period of the installation allowed to establish the sequential and global treatment efficiency in respect to the analysed indicators.

The installation's effluents presented organic loads varying from:

-***Stage I***: COD = 760 – 300 mgO_2/L; BOD_5 = 190 – 50 mgO_2/L;

-***Stage II (final effluent)*****:** COD = 461 – 61 mgO_2/L; BOD_5 = 86 – 9 mgO_2/L;

During the experiment, the final effluents were characterised for all the parameters imposed at discharge into municipal sewerage network (table 3). It can be seen that the final effluent quality is in compliance with the limits imposed by GD 352/05-NTPA002 for indicators: pH, COD, BOD_5, suspensions, non-ionic detergents, total phosphorus, ammonium.

Treatment efficiencies were in the range of:

-***Stage I***: η COD = 45 – 95 %; η BOD_5 = 67 – 96 %;

-***Stage II*****:** η COD = 3 – 80 %; η BOD_5 = 25 – 85 %;

-***Total***: η COD = 63 – 97 %; η BOD_5 = 82 – 99 %;

The evolution of COD and BOD_5 biodegradation efficiencies (sequential and global) during the experiment is shown in figures 3 and 4.

Table 3

CHARACTERISTICS OF BIOLOGICAL TREATMENT INSTALLATION FINAL EFFLUENT (VARIATION DOMAINS)

No.	Characteristics	Final effluent	NTPA 002
1	pH	7,0 – 8,5	6,5 – 8,5
2	COD, mgO_2/L	61 - 461	500
3	BOD_5, mgO_2/L	9 - 86	300
4	Suspensions, mg/L	88 - 140	350
5	Non-ionic detergents, mg/L	4.53 – 12.2	25
6	P_t, mg/L	2.28 – 3.61	5
7	NH_4^+, mg/L	0.54 – 3.46	30

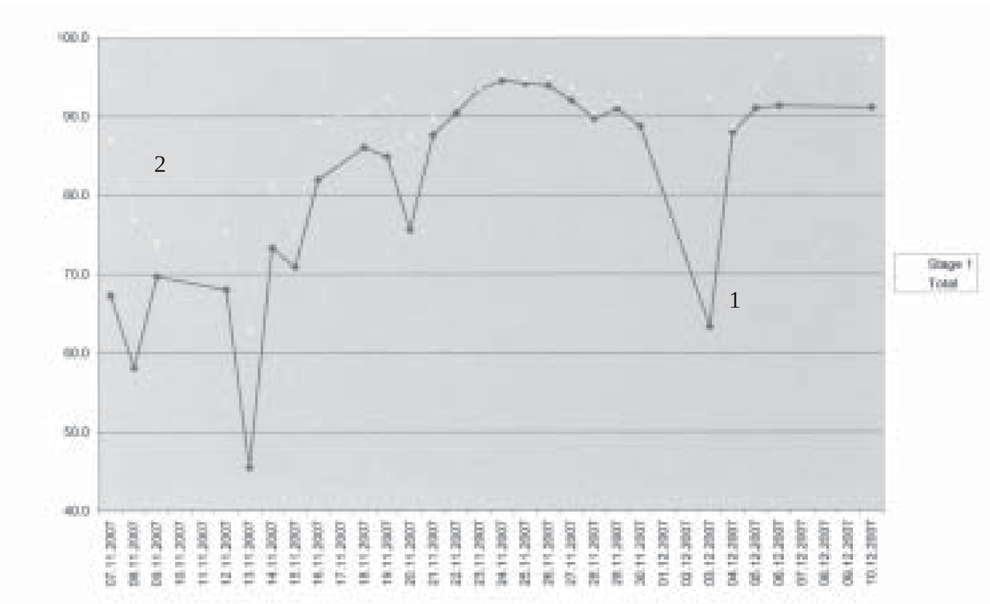

Fig. 3. The evolution of COD biodegradation efficiencies (sequential and global) vs. time

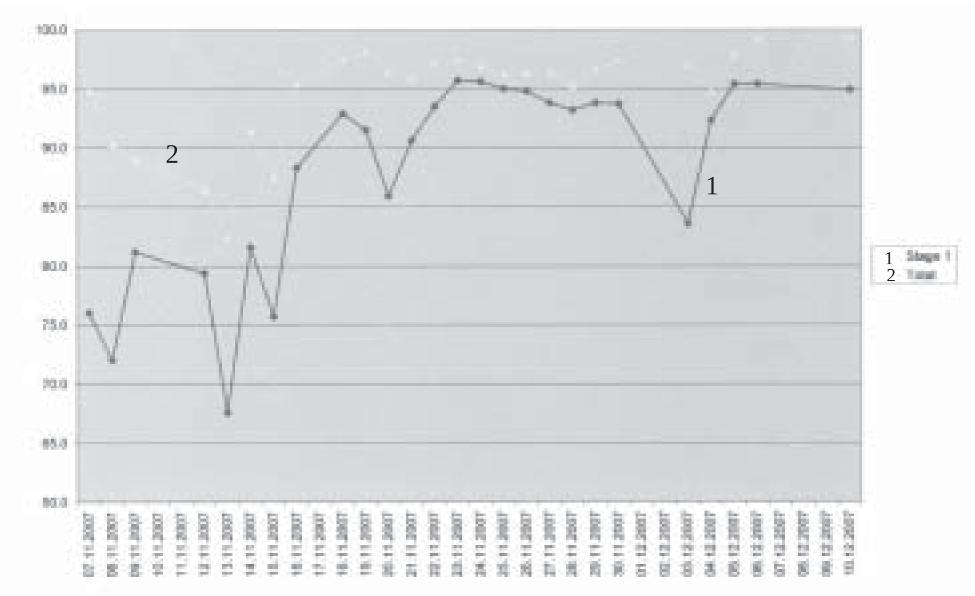

Fig. 4. The evolution of BOD_5 biodegradation efficiencies (sequential and global) vs. time

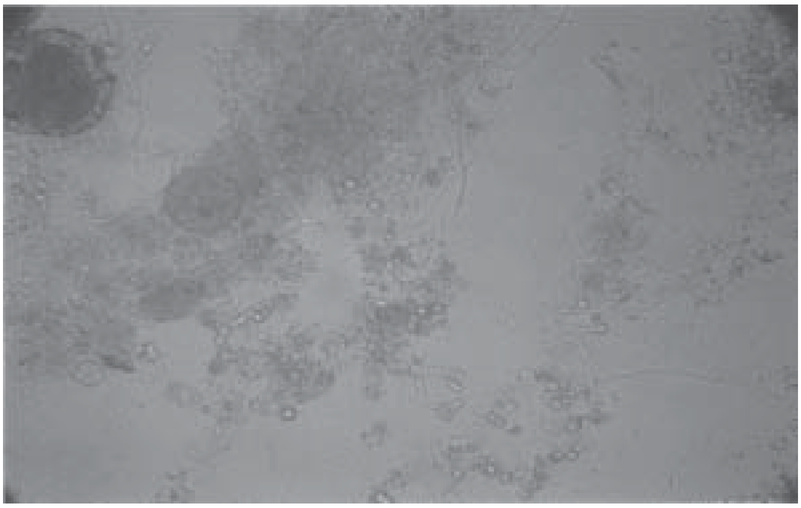

Fig.5. Microscopic aspect of activated sludge *in first treatment stage* – small ciliates

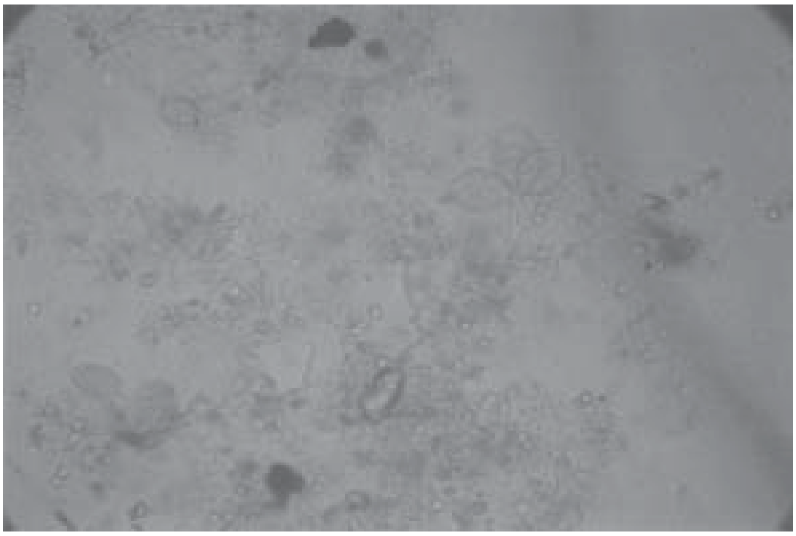

Fig. 6. Microscopic aspect of activated sludge *in stable regime operation* – solitary peritriche ciliates (*Vorticella sp.)* and colonial fixed ciliates (*Carchesium sp.)*

The morpho-physiologic characterisation of biocenosis

Installation operation was also monitored via microspe analyse of morpho-physiologic aspect of activated sludge biocenosis, both for first and second treatment stages.

Biologic sludge samples from both reactors of the pilot installation analysed via microscopy, various stages of the experiments, showed the following aspects:

Stage I

- Due to the high abundance of food (1st stage being the high load step), there is a predominance of small free holotriche ciliates, especially during the initiation period of the treatment installation (fig. 5);

As time goes by, when the installation is entering the equilibrium, the number of free ciliates is decreasing, and fixed solitary ciliates are appearing (*Vorticella* sp), as well as colonial fixed ciliates from genders (*Carchesium and Epistylis*) (fig. 6).

Stage II

- Small and medium flocs, constituted from bacteria groups (mark 4-5), free bacteria (mark 1, small number as in first stage) and rarely filamentous bacteria (mark 1).

- Diversified micro-fauna, represented by small free ciliates (*Colpoda sp.* and *Glaucoma sp.)* – , hypotriche ciliates, from genders *Aspidisca*, *Euplotes* and *Oxytricha*

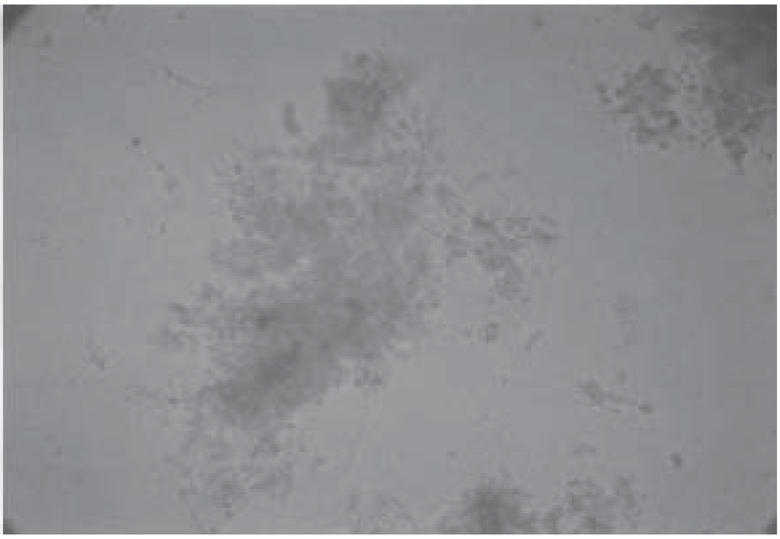

Fig. 7. Microscopic aspect of the sludge *in second treatment stage* – bacteria groups, free ciliates

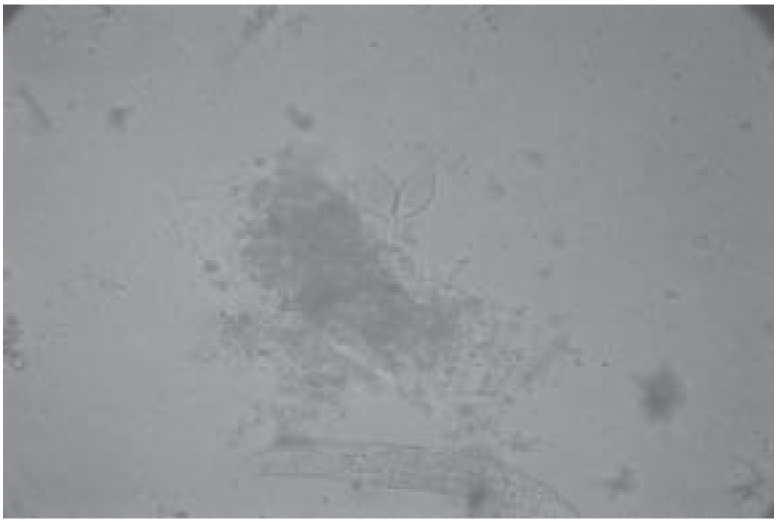

Fig. 8. Microscopic aspects of the sludge in second treatment stage – fixed ciliates, hypotriche free ciliates (Aspidisca sp.), rotaria

and peritriche fixed ciliates, from genders *Vorticella*, *Carchesium* and *Epistylis*. Metazoars were represented by two rotaria genders (*Lecane* and *Rotaria)* and nematodes (fig. 7 and 8).

Diversified micro-fauna and *presence of hypotriche ciliates* in the activated sludge are showing a good treatment and it is in correlation with obtained experimental efficiencies. The presence of rotaria is showing a stabilised and well oxygenated sludge (dissolved oxygen concentration was maintained for the whole experiment's period at values between 2.5 and 4.5 mg O_2/L). The biological sludge from both stages it was observed to be healthy, well flocculated, with numerous bacteria groups. Activated sludge is presenting goods settling properties, the sludge volume index (SVI) being below 150 mL /g.s.d.s.

Processing of in excess sludge

The in excess sludge resulted from biological treatment (10-12 g d.s./L) was stabilised via aeration (τ= 15 days, O_2 = 2 mg/L), the efficiency of volatile compounds reduction being of about 50%.

In order to reduce the sludge volume with 80-90%, the sludge was conditioned in two variants: with lime (lime 10% CaO = 20 mL/L sludge) and with strong cationic polyelectrolyte (PEC sol. 0.1%, 16 mL/L sludge) and then dewatered via centrifugation (acceleration 1000 g, τ = 5 min.).

Due to its biological nature, the loss on ignition (LOI = 69.6%) are situated above the value for hazardous sludge set by Order 95/2005 (LOI = 10%).

Even if the analyse of the obtained leachate (ratio L/S = 10/1, L = leachant distilled water, τ = 24 h) is not showing DOC (dissolved organic carbon) values above the limit (DOC < 800 mg/kg d.s.) set up by the Order 95/2005 as criteria for the waste to be accepted within non-hazardous waste storage, due to the LOI value above the admissible norm, the sludge is proposed to be incinerated.

Conclusions

The municipal and industrial wastewater treatment concept became more specific and diversified, along with industrial development and growth of urban population. In this context, the technological research in the field of wastewater treatment led to development of intensive, specialised processes, including sequential bioreactors, which were developed during the last decades.

The sequential reactors pilot installation (SBR) used to perform the treatment experiments for industrial wastewater generated from drugs fabrication, was designed and built by the technological engineering group of INCD ECOIND. From the advantages presented by a intensive treatment system with sequential bioreactors (SBR) in comparison with continuous flow feeding systems, it can be mentioned: flexibility in operation, reduced construction and maintenance costs, good solids retention, efficient operation control and absence of secondary settlers.

The results of experimental research works carried on two-stage SBR installation (at HRT = 9 h) showed the following aspects:

-significant reduction of wastewater' organic load (COD = 1200 – 3300 mg O_2/L, BOD_5 = 490 - 1570 mg O_2/L) is performed within the stage I (SBR_1), the high load step, maximum removal efficiencies being of 95-96%;

-the organic load of the stage I effluent is varying within the following domains: COD = 300-760 mg O_2/L, BOD_5 = 50-190 mg O_2/L;

-within the treatment stage II (SBR_2), theoretically considered as a finishing stage, the maximum removal efficiencies of COD and BOD_5 didn't exceed 85%, the effluents organic load being within the concentration domains admitted for discharge into municipal sewerage network. For advanced treatment, in order to comply with the exigencies of the imposed limits for discharges into natural receivers (GD 352/2005-NTPA001), future research works on biomass fixed on support alternative are considered. (SBBR);

-the in excess biological sludge, after stabilisation – conditioning – filtration (centrifugation), is directed to the incineration, due to the fact that is not in compliance with the legislation imposed for controlled storage.

The biological treatment technology in an intensive SBR reactor type can be transposed at industrial level for the treatment of industrial wastewater resulted from drugs fabrication (conditioning processes). Its applicability can also be extended to other wastewater categories, with high organic loads, after preliminary testing.

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