Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.878254

52 (2014) 2315–2321
February

Taylor & Francis
Taylor & Francis Group

Contribution to biological treatment of dairy effluent by sequencing batch reactor (SBR)

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Received 2 February 2013; Accepted 13 December 2013

ABSTRACT

The treatment of dairy effluent, strongly loaded with biodegradable matter, can help protect the environment, when the purified water will be used for irrigation and the sludge produced valorized through agricultural use. The purpose of this study was to investigate the removal of organic matter (as COD) from synthetic dairy wastewater in a sequencing batch reactor which depends on three main factors: aeration time; volume load (VL), and organic loading (OL). Results show that whether the COD of the effluent to be treated varies from 220 to 7000 mg O_2/l, the COD of the treated effluent is reduced when aeration time increases. For low COD levels, below 2640 mg O_2/l, 20 h of aeration time appears to be an optimum value ensuring an effluent composition very much in line with the discharge standards (≈120 mg O_2/l). For higher applied organic loads, up to 7000 mg O_2/l, the aeration time required is longer. Thus, it takes 48 h to reduce 7000 mg O_2/l to a value hardly consistent with the discharge standards. The nature of the sludge produced (filaments) and the settling time limit the process performance. It is also noted that the COD removal efficiency depends more on the VL values than on the applied OL. For VL values ranging from 0.130 to 4.36 kg COD/m^3/d and OL values between 0.08 and 3.46 kg COD/kg MLVSS/d, performance is inversely proportional to the applied loads and varies roughly from 65 to 96% for VL and from 90 to 99% for OL.

Keywords: Food processing effluents; Dairy wastewater; Biological treatment; Sequencing batch reactor

1. Introduction

In Algeria, many food industries, which are large water consumers, unable to ensure treatment of their highly polluting liquid effluents, discharge them directly in rivers, especially in times of drought. This is the case of a dairy and cheese factory located in the region of Tizi-Ouzou (Algeria) which discharges an average of 1,200 m^3/d of wastewater into the quasi-permanent low-flow water of the Sebou River. These effluents, characterized by flow and concentration

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Presented at the 6th International Conference on Water Resources in Mediterranean Basin (WATMED6), 10–12 October 2012, Sousse, Tunisia

variability, constitute an essentially organic and easily biodegradable pollution in a dissolved form, estimated at 4,270 mg O_2/l as COD. The pollution due to these discharges, equivalent to 48,000 inhabitants, corresponds to a $438.10^3\,m^3$/year outflow and an annual output of 1,825 tons of organic matter (measured in COD). The treatment of these effluents can help protect the environment, when the purified water will be used for irrigation and the sludge produced valorized through agricultural use. The sequencing batch reactor (SBR) process has been successfully applied to domestic and food process wastewaters by other researchers [1–13]. For dairy effluents, the applied organic load can reach 12 g O_2/l [1].

The process, which has the advantage of being compact, is particularly well suited for cyclic effluents. The comparison of different biological processes for the treatment of dairy effluents and more generally food industry effluents has shown that SBR is the most efficient [2].

The batch mode allows the coupling of the hydraulic residence time and the sludge residence time, the reactor acting as a decanter. Indeed, SBR allows the removal of 99% of organic matter, 100% of total suspended solids (TSS), 94% of Kjeldahl nitrogen, and 87% of total phosphorus. In addition to the high treatment efficiency, the advantages of SBR are its low investment and maintenance costs, scalability, adaptability, and automation. If the expenses related to the SBR installation are advantageous, the operating costs are unfavorable (high energy consumption) [3,4].

The influence of the aeration cycle number and of the tank bottom volume (stored sludge volume) between each cycle on treatment performance in the case of very heavily applied volume loads (VL) from 1.7 to 5.4 kg COD/m^3/d has been studied by [2]. The reactor total volume is 2 l and the tank bottom volume is 0.45 l. Biodegradability tests have been performed with various effluent models elaborated with whole milk diluted 50 times, amended or not [2].

The incoming effluent presents a high COD content from 2,900 to 3,675 mg O_2/l, a pH oscillating from 6.47 to 7.56, and TSS from 1.08 to 3.33 g/l. The results on treated effluent show soluble COD values from 0 to 550 mg O_2/l, pH levels from 6.52 to 8.25, and TSS from 0.73 to 4.3 g/l.

For the activated sludge, the applied VL ranges from 0.5 to 10 kg COD/m^3/d. The aerobic treatment produces from 0.3 to 0.5 kg of sludge (expressed as dry matter) per kg COD removed, depending on the process used [12].

Often, an anaerobic pre-treatment is used to remove a very large portion of the pollutant load, then an aerobic treatment can lower the residual biochemical oxygen demand (BOD) and COD, and finally a biological nutrient removal process is applied. The mixture of biogas, consisting of methane (CH_4) and carbon dioxide (CO_2), produced during the anaerobic treatment can be recovered and used in place of fossil fuel [12]. In an anaerobic system, sludge production does not exceed 0.05 kg of sludge (expressed as dry matter) per kg COD removed. The biogas can be used as an extra energy source for the process [7,9].

The low sludge production is the most important point and has interesting economic consequences related to the reduced volume of the reactor and reduced volume of sludge to be treated at the end of the process. However, anaerobic treatments are often unable to sufficiently reduce BOD and an aerobic post-treatment must often be considered. This is the main limitation of anaerobic treatments.

In the aerobic treatment of food effluents, SBR can be applied at rates of up to 20,000 m^3/d, with an organic loading (OL) rate of 0.15 kg COD/kg MLVSS/d and hydraulic residence time exceeding 14 h [13]. The SBR process returns are from 20 to 30% lower than those of the conventional activated sludge system for similar effluent quality. The required basin volumes are estimated to be 0.45 m^3/equivalent inhabitant for SBR and 0.24 m^3/EH for conventional processes [13].

The purpose of this study was to investigate the COD removal from synthetic dairy wastewater in a SBR. COD removal was studied in dependence of three factors: aeration time, VL, and OL. The initial COD content of the effluent was varied from 220 to 7,000 mg O_2/l corresponding to a load value comprised between 0.13 and 4.36 kg COD/m^3/d or 0.075 and 2.52 kg BOD_5/m^3/d. The aeration time was varied from 4 to 48 h.

2. Materials and methods

2.1. Characterization of the dairy effluent

The average composition of the dairy wastewater, given in Table 1, shows that the effluent had a very high organic load with COD and BOD_5 averages, respectively, equal to 4,270 and 2,460 mg O_2/l and maximum values up to 7,500 mg O_2/l as COD and 4,800 mg O_2/l as BOD_5. If, in accordance with [14], we consider that the average BOD_5 of domestic effluents is 300 mg O_2/l, it appears that dairy effluents are about eight times more concentrated.

If we refer to the average values of COD and BOD_5 of whole milk produced by the dairy concerned, evaluated, respectively, at 133 and 76 g O_2/l, we can also consider that the wastewater of the dairy represents about 30 times diluted milk, cf. Table 2.

Table 1
Average composition of the dairy effluent [16]

Parameters	Units	Average values	Extreme values	Algerian standard values *a* for wastes discharged in river
Temperature	°C	25	30	30
pH	/	6	3–11	6.5–8.5
TSS	mg/l	587		30
BOD_5	mg O_2/l	2,460	4,800	40
COD	mg O_2/l	4,270	7,500	120
BOD_5/COD	/	0.58		
Fat	mg/l	120		
N Total	mg/l	150		40
N (NH_4^+)	mg/l	8.47		
N (NO_3^-)	mg/l	20–45		
P total	mg/l	90		2
$(PO_4)^{3-}$	mg/l	21		

The average organic matter content in the milk produced by the dairy, expressed as BOD_5, is less than that given by [14] for milk, that is, about 100 g O_2/l. The volume of wastewater discharged by dairies (diluted milk from cleaning operations + whey) is 4.2 l per liter of milk produced and the COD is about 14 g O_2/l of effluent [4]. Biodegradability coefficient as BOD_5/COD, which nears 0.58, reflects the efficiency of the biological treatment of these effluents. The presence of fats upsets the biological treatment of water because the kinetics of aerobic fat degradation is slow.

2.2. Reactor description

The reactor used consisted of a single plexiglass basin of a total volume of 5 l. It was connected to: (a) a substrate feed pump, (b) a pump for drawing off excess sludge, and (c) an air compressor for supplying oxygen for the biomass aeration through a fine bubble diffuser.

The basin was equipped with a paddle stirrer (up to 50 rpm) to homogenize the mixed liquor during aeration, in order to prevent the formation of deposits on the reactor walls without causing shear damage to the micro-organisms that would reduce their activity. Two electrodes submerged in the reactor allowed continuous measurement of the temperature, pH, and dissolved oxygen content. The dissolved O_2 content could be changed at any time by changing the aeration rate and agitation speed. The experiments were performed at room temperature without changing the pH. The samples for analysis and the supernatant drain were siphoned off.

Table 2
Average values of the parameters of the milk produced by the dairy [16]

pH	BOD_5 (g O_2/l)	COD (g O_2/l)	NH_4^+ (mg/l)	NO_3^- (mg/l)	PO_4^{3-} (mg/l)
7.4	76.00	133.00	62.71	408.85	435.71

2.3. Methods

2.3.1. Seeding of the reactor

The seeding of the reactor was carried out with a biomass from the activated sludge of the urban wastewater treatment plant of Tizi-Ouzou, according to the protocol described by [2]. The sludge was collected from the aeration basin. Its TSS fresh weight varied from 4 to 10 g/l. It was aerated for 2 h so that the micro-organisms removed most part of the substrate remaining in the endogenous area. The sludge was then centrifuged for 10 min. The fresh weight of the inoculum used to seed the SBR varied from 10 to 20 g.

The adaptation of the biomass to the milk substrate was done gradually by injecting increasing doses of synthetic effluents into the SBR. During the procedure of acclimation of the activated sludge to the milk substrate, the COD concentration increased by steps of 50 mg O_2/l up to an increase of 200 mg O_2/l. The experimental assays then began.

2.3.2. Synthetic dairy effluent

In order to represent the wastewater generated by the dairy, effluent samples were prepared from the milk produced by the dairy by diluting it with water from the supply network of drinking water without adding any other product, neither acidic nor basic reagents used in cleaning operations. The use of synthetic wastewater was justified by the technical difficulties related to the collection and transport of the samples. In principle, they contain only milk elements, mainly proteins (caseins, albumin, and globulin), undissolved fat particles, nitrogen, and phosphorus (Tables 1 and 2).

2.3.3. Method of analysis

The assessment of the treatment performance of the biological reactor consisted of measuring input and output temperature, pH, TSS, MLV*SS*, COD, and BOD_5. The samples were centrifuged before COD and

BOD measurements. The analytical methods used are given by [15].

2.3.4. Implementation of the assays

The block diagram of the SBR is shown in Fig. 1.

After being sown, the reactor was first filled in a single step with 2–3 l of the synthetic effluent to be treated. It was then aerated and agitated for a predetermined period. It was finally allowed to settle for a constant period (2 h).

The supernatant obtained, before being drained, was characterized in order to evaluate the treatment process performance. According to the biomass content which we want to obtain in the reactor, the settled sludge can be partially withdrawn to maintain the necessary biomass content. All these operations represent a course of treatment.

Each experimental test corresponded to a single cycle of operation previously preceded by the total drain of the supernatant; only the sludge volume in the reactor was kept between 1 and 2 l, that is, 20–40% of the useful volume. Table 3 summarizes the operating conditions for all the tests. The performances of the reactor were determined under the influence of the aeration time, the VL, and the OL of the effluent to be treated.

The correlation between these variables relies on the two following operating parameters:

The VL, which is written: $VL = S_0\ Q/V$

The OL, which is written: $OL = S_0\ Q/VX^{\circ}$

VL in (kg $BOD_5/m^3/d$)

OL in (kg BOD_5/kg MLVSS/d)

S_0 = initial concentration of effluent to be treated (kg BOD_5/m^3)

Q = flow of the effluent to be treated (m^3/d)

V = useful volume of the reactor (m^3)

X = biomass concentration in the reactor (kg MLVSS/m^3).

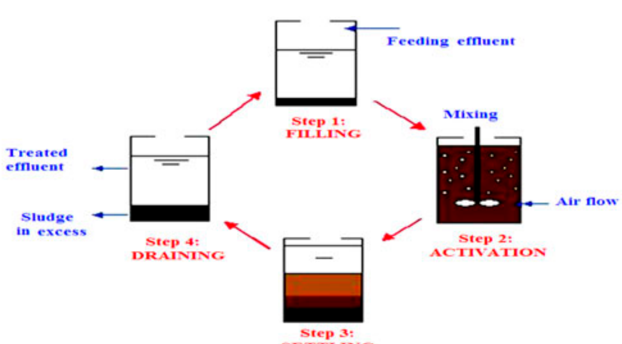

Fig. 1. Block diagram of the SBR [2].

Table 3
Main operating parameters of the reactor

Parameters	Values	Units
Total volume	3–5	l
Treated volume	2–3	l
Initial settled sludge	1–2	l
Aeration time	4–48	h
TSS (total suspended solids content in the reactor)	0.72–5.8	g/l
Applied BOD_5	127–404.6	mg O_2/l
Applied COD	220–7,000	mg O_2/l
Volume load (VL)	0.075–2.52	kg $BOD_5/m^3/d$
	0.130–4.36	kg COD $/m^3/d$
Organic loading (OL)	0.05–2	kg BOD_5/kg MLVSS/d
	0.08−3.46	kg COD/kg MLVSS/d
Dissolved O_2 content	2–5	mg O_2/l
pH	7.02–7.96	
Temperature	20 ± 5	℃

3. Results and discussion

3.1. Influence of aeration time and COD concentration

Figs. 2 and 3 show that, whether the influent COD varies from 220 to 7,000 mg O_2/l, the residual COD of the treated effluent is reduced when the aeration time increases.

In general, there is an initial phase of rapid degradation when the aeration time is less than 20 h, without any latency period, followed by a slowdown. For low concentrations of initial COD below 2,640 mg O_2/l of the synthetic effluent, an aeration time of 20 h is sufficient to ensure an effluent composition that largely complies with discharge standards (Figs. 2(a) and 3(a)).

The same result is obtained by treating the real effluent rejected by the dairy with SBR [11].

This result shows that choosing a SBR is more advantageous than choosing the conventional activated sludge process used by [16] and [17], which requires 20 h of ventilation with 100% recycling to eliminate 1,250 mg O_2/l as COD.

The required aeration time is the most important factor for high initial COD values up to 7,000 mg O_2/l, Fig. 2(b). Thus, it takes 48 h of aeration to reduce 7,000 mg O_2/l to a value higher than 120 mg O_2/l, which is not in compliance with the discharge standards (Figs. 2(b) and 3(b)). However, this aeration time obtained with a SBR is significantly lower than the 4.5 days of ventilation required by the activated sludge process developed by [18] to treat dairy effluent of 6,210 mg COD/l.

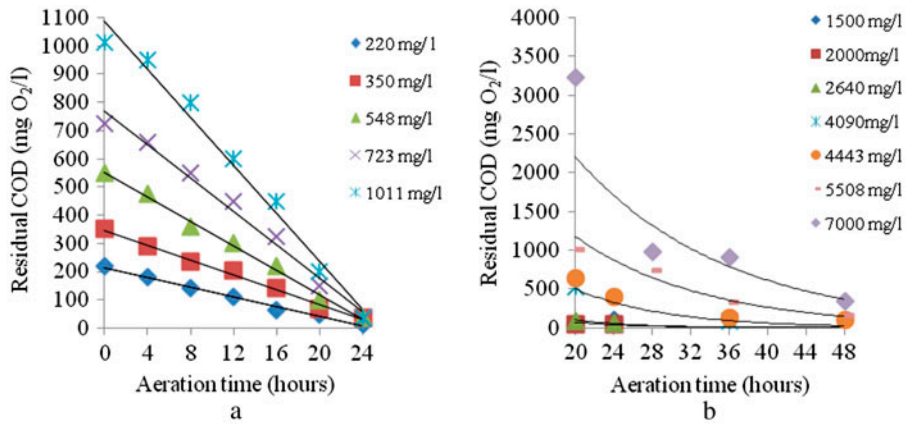

Fig. 2. Effect of the aeration time at: (a) initial low COD values (220–1,011 mg O_2/l) and (b) initial high COD values (1,500–7,000 mg O_2/l) on residual COD content.

Fig. 4 shows that the efficiency increases whith the aeration time and decreases when the input COD content increases.

3.2. Volume load effect (VL)

Tests were performed with VLs from 0.075 to 2.52 kg BOD_5/m^3/d, corresponding to 0.130–4.36 kg COD/m^3/d. Fig. 5(a) shows that the residual COD is an exponential function of the VL up to 2.52 kg BOD_5/m^3/d. Beyond 1.2 kg BOD_5/m^3/d, the residual COD exceeds discharge standards.

Fig. 5(b) shows that the organic pollution removal efficiency is greater than 95% for average loads (VL ≤ 1.2 kg BOD_5/m^3/d). For an applied COD load of 7,000 mg O_2/l, the efficiency is around 96% and the VL corresponds to 1.2 kg BOD_5/m^3/d. This high efficiency corresponds to the results reported by [3] and [8]. However, these performances appear higher than those obtained by [2] on treatment with SBR of a similar effluent, giving an input COD between 2,900 and 3,675 mg O_2/l corresponding to a VL between 1.7 and 5.4 kg COD/m^3.d. The experiment carried out by [2] took place over 248 h with 15 cycles performed on a sequence average of 10 h of aeration and 1.5 h of settling. The values of dissolved COD reached at the end of the cycle are generally about 300 mg O_2/l; they are higher than the discharge standard values and do not provide effluents sufficiently clarified because of settling difficulties.

3.3. Organic loading effect (OL)

Fig. 6(a) shows that the COD of the treated effluent increased slowly with the value of the applied mass load beyond 0.25 kg BOD_5/kg MLVSS/d. The

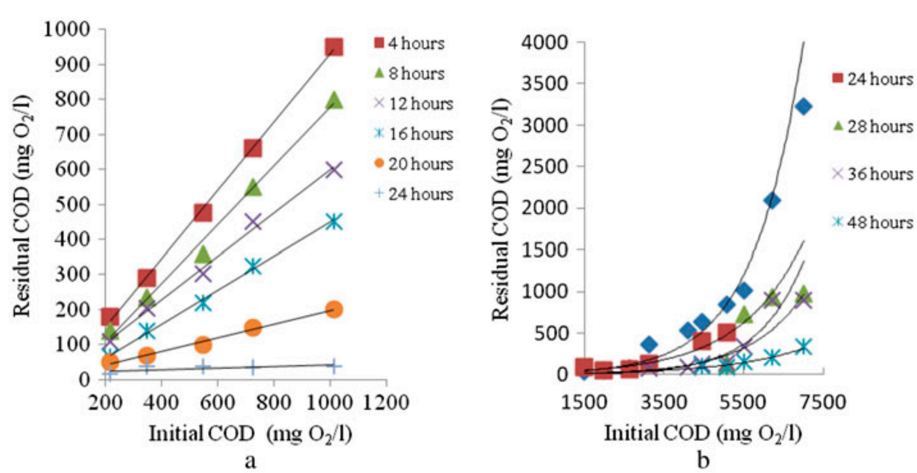

Fig. 3. Effect of initial COD content at: (a) low COD values (220–1,011 mg O_2/l) and (b) high COD values (1,500–7,000 mg O_2/l on residual COD content.

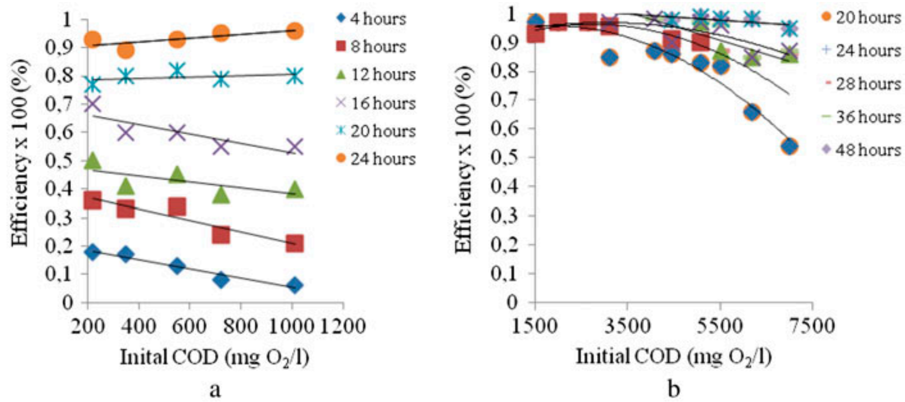

Fig. 4. Effect of initial COD content at: (a) low COD values (220–1,011 mg O_2/l) and (b) high COD values (1,500–7,000 mg O_2/l) on efficiency of COD removal.

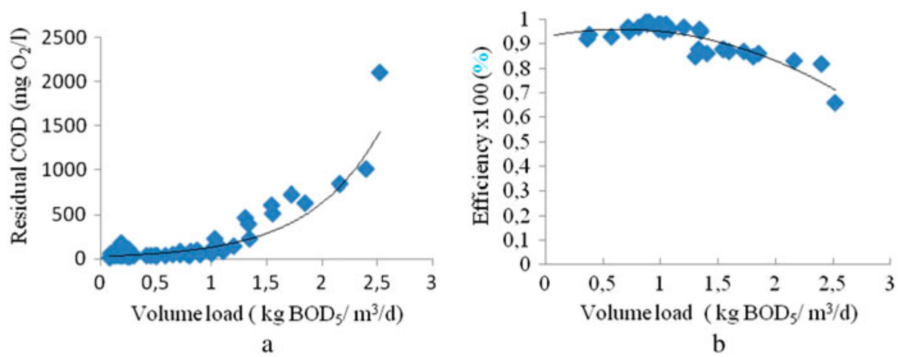

Fig. 5. VL effect on: (a) residual COD and (b) efficiency of COD removal.

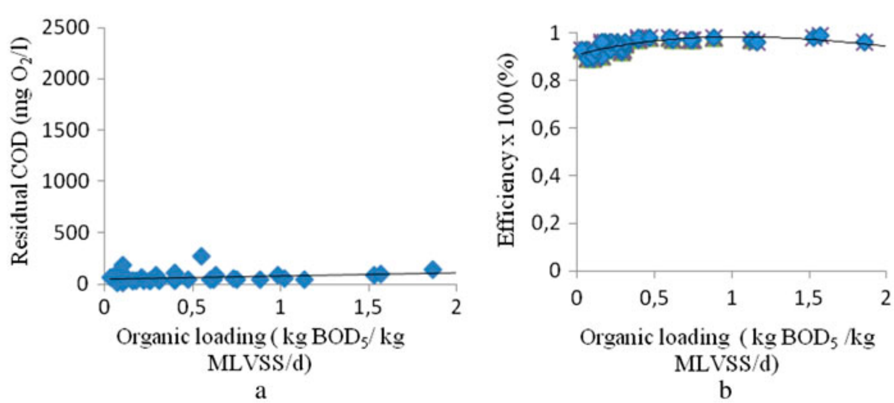

Fig. 6. Effect of OL on: (a) residual COD and (b) COD removal efficiency.

efficiency of the process reaches 100% but starts decreasing when the applied mass load exceeds 1.2 kg BOD_5/kg MLVSS/d, Fig. 6(b).

The TSS content in the bioreactor was controlled by the level of the settled sludge starter maintained between two successive supernatant draining operations. Depending on the tests, it fluctuated between 0.72 and 5.8 g/l. In the absence of withdrawal, it mainly depended on the growth of the activated sludge and the nature of the effluent. When the COD load applied was high, TSS control became difficult because of the bad settling of the sludge, which remained in the supernatant after the settling phase. The settling time became the main factor influencing the performance of the process. Activated sludge bulking, characterized by a high Mohlman index (IM ≥ 150), was observed.

4. Conclusion

The results show that the use of the SBR for dairy wastewater treatment is appropriate. Indeed, with 48 h aeration, 2 h decanting, and the initial sludge volume in the reactor maintained between 20 and 40% of the useful volume, the SBR can treat up to 7,000 mg O_2/l effluent with 96% of efficiency.

However, the settling time, set at 2 h, limits sludge settling and does not allow more than 1.2 kg BOD_5/m^3/d, that is, about 2 kg COD/m^3/d, to be removed.

The aerobic treatment of the real dairy effluent by SBR, when the flow and the COD values are, respectively, estimated at 1,200 m^3/d and 70,000 mg O_2/l, is not economically justified. The reasons are the high energy consumption, the large reactor volume needed, and the long aeration time (48 h).

The initial high organic matter concentration in dairy effluent requires pre-treatment under anaerobic conditions before the aerobic phase. This will be the next step of this study.

References

[1] E. Bouille, V. Dubois, M. Egal, P. Herpin, P. Porterie, O. Senesse, R. Vales, Traitement, épuration et valorisation des effluents d'une fromagerie: étude du procédé de traitement des effluents [Treatment and valorization of cheese dairy effluents], ENSEEIHT, Toulouse, France, 2005 (in french).

[2] S. Castillo de Campins, Etude d'un procédé compact de traitement biologique aérobie d'effluents laitiers [Study of a compact, aerobic, biological treatment of dairy effluent] (PhD thesis), INSA, Toulouse, French, 2005 (in french).

[3] T. Corthondo, F. Trépos, Traitement d'effluents laitiers, 2004. Available from: www.apesa.fr/iso_album/traitement d'effluents laitiers.

[4] J.B. Dolle, Mise au point de procédés de traitement de lactosérum et d'effluents de fromagerie en fabrication fermière [Treatment of wheys and cheese dairy effluents in manufacturing farms], Institut d'élevage, Saint Laurent Blangy, France, 2003 (in french).

[5] M. Merzouki, Contribution à l'optimisation du traitement biologique des effluents agroalimentaires par le réacteur séquentiel discontinu [Contribution to the optimization of the biological treatment of food industries effluents by the sequential batch reactor], Eurodeur—ECGP'6, Marseille, France, 2007 (in french).

[6] M. Torrijos, B. Gsell, R. Moletta, Application du procédé SBR au traitement des effluents de petites coopératives laitières [Application of the SBR process in the wastewater treatment of small dairy factories], l'Eau, l'Industrie et les Nuisances 202 (1997) 31–35 (in french).

[7] M. Torrijos, B. Gsell, R. Moletta, Application d'un procédé SBR anaérobie et aérobie au traitement carboné et azoté du lisier [Application of an anaerobic and an aerobic SBR to the wastewater treatment of manures], L'Eau, l'Industrie et les Nuisances 212 (1998) 56–59 (in french).

[8] M. Torrijos, V. Vuitton, R. Moletta, The SBR process: An efficient and economic solution for the treatment of waste water at small cheese making dairies in the Jura mountain, in: 2nd International Symposium of Sequencing Batch Reactor Technology, Vol. I, Narbonne, France, 1998, pp. 400–408.

[9] M. Torrijos, B. Gsell, R. Moletta, P. Degene, High COD wastewater treatment in anaerobic SBR: Treatment of effluent from a small farm goat's cheese dairy, Water Sci. Technol. 50(10) (2004) 259–267.

[10] R. Moletta, M. Torrijos, Traitement d'effluent laitiers, Technique de l'ingénieur [Treatment of the dairy's wastewater] F1 501 (1999) 1–21. Paris (in french).

[11] H. Yahi, N. Madi, K. Midoune, Traitement d'effluents agro alimentaires par réacteur biologique séquentiel [Treatment of food industries wastewater by a sequential biologic reactor], in: Fifth International Conference on the Water Resources in Mediterranean Basin , Lille, France, 2010 (in french).

[12] E. Houbron, M. Torrigos, R. Moletta, SBR, technologie appliquée aux effluents vinicoles [SBR, applied technology to wineries wastewater treatment], in: Second International Congress on the treatment of wastewaters, Edition of Cemagref Anthony, Bordeaux, Paris, France, 1998 (in french).

[13] P. Peinger, Réacteur biologique séquentiel: modélisation des procédés pour l'environnement édition de l'Ecole Polytechnique de Lausanne [Sequencing batch reactor: Engineering and modeling of environmental bioprocesses], Federal polytechnic School of Lausanne, Lausanne 2004 (in french).

[14] Degrémont, Mémento technique de l'eau [Technical memento of water], 10éme éd., Degrémont, Suez, Paris, 2005 (in french).

[15] J. Rodier, B. Legube, N. Merlet, L'analyse de l'eau: eaux naturelles, eaux résiduaires et eau de mer [The analysis of the water: Natural waters, wastewaters, sea water], Collection technique de l'Ingénieur, 9éme éd., Dunod, Paris, 2009 (in french).

[16] H. Yahi, A. Hami, Caractérisation et traitement biologique par boues activées d'effluents laitiers [Characterization and biological treatment by activated sludge of a dairy effluent], Algerian J. Technol. 2 (2008) 571–580. (Algiers, in french).

[17] H. Yahi, K. Merrouki, Traitement biologique d'effluents agro-alimentaires à forte charge organique [Biological treatment of food industries effluents with high organic load], in: Nineth Conference of the French Group of the International Humic Substances Society (IHSS), Montpellier, France, 2009 (in french).

[18] S. Sadou, Traitement biologique par boues activées d' effluents agro alimentaires à forte [Biological treatment by activated sludge of food industries effluents with high organic loading] (Thesis of Agronomical Sciences). Mouloud Mammeri University, Tizi-ouzou, Algeria, 2009 (in french).