Pergamon

Wat. Sci. Tech. Vol. 35, No. 1, pp. 193–198, 1997.

0273–1223/97 \$17·00 + 0·00

PII: S0273-1223(96)00896-7

FEASIBILITY OF A PULSED SEQUENCING BATCH REACTOR WITH ANAEROBIC AGGREGATED BIOMASS FOR THE TREATMENT OF LOW STRENGTH WASTEWATERS

A. G. Brito, A. C. Rodrigues and L. F. Melo

Department of Biological Engineering, University of Minho, Largo do Paço, P-4709 Braga, Portugal

ABSTRACT

This study concerns an assessment of a SBR operation that associates anaerobic aggregated biomass with a pulsed action during the reaction phase, a system named Pulsed Sequencing Batch Reactor (P-SBR). The system uses a diaphragm pump as a pulsator unit to increase the liquid-solid contact, in order to avoid dead zones and possible external mass transfer resistance. A preliminary study of the operation of the reactor was performed with a low strength synthetic wastewater with a COD near 1000 $mg.l^{-1}$ and a sub-optimal temperature of 22°C. A removal efficiency of 60-70% was attained after 5 and 6 hours of reaction time. The respective organic loads were 5 - 6 kg $COD.m^{-3}.day^{-1}$, thus supporting the feasibility of the P-SBR system for wastewater treatment in such conditions. The results also indicate that a ratio of 1.8‰ between the swept volume delivered by the pump and the reactor volume was adequate to promote a flow turbulence in the sludge blanket and that a redox potential of near -400 mV was readily created by anaerobic bacteria after the reactor filling step. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Anaerobic treatment; low strength wastewaters; SBR reactors; pulsed reactors; granules; sub-optimal temperature.

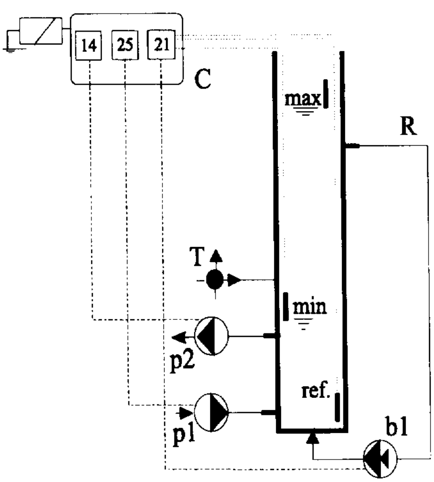
INTRODUCTION

The anaerobic technology should always be part of the list of process options for an industrial wastewater treatment because, when proficient, it saves energy and minimises sludge disposal costs.An anaerobic reactor that accounts for a significant number of full-scale systems is the Upflow Anaerobic Sludge Blanket reactor (Lettinga and Hulshoff Pol, 1992). Its operation mode induces the development of a biological self-aggregation process without addition of support material. The resulting biofilm structure is usually denominated "granules" and is considered to be the main factor for their high biomass concentration and activity. The anaerobic treatment of industrial effluents with COD levels above 1500-2000 $mg.l^{-1}$ is well accepted (Pfeiffer *et al.*, 1986). However, wastewaters from municipalities and several industries have a lower organic concentration, some are discharged at ambient temperatures and in fact just a few full-scale anaerobic reactors have been used for the treatment of such wastewaters, (Draiier *et al.*, 1992, Schellinkhout and Collazos, 1992). Sequencing Batch Reactors (SBR) have been developed in aerobic systems (Irvine *et al.*, 1977). Sung and Dague (1992) expanded the potential of the SBR technology by presenting an anaerobic system with gas recirculation for mixing during the reaction phase. The anaerobic SBR approach seems to be suitable for the on-site treatment of medium-high strength effluents. However, in low strength wastewaters there is a potential problem due to the fact that the available gas production will be rather low, especially at ambient temperatures. A weak gas production will result in an insufficient turbulence in the reactor, thus increasing the possibilities of stagnant zones and/or external mass transfer resistance. Stadlbauer *et al.* (1992) indicated that a high-pulsed system incorporated in an anaerobic filter and in a horizontal baffled filter could favour degassing from carriers and circumvented clogging and channelling in the reactors.

Therefore, the present study is concerned with the initial assessment of a SBR operation protocol that combines anaerobic granules with a pulsed action during the reaction stage, in a system named Pulsed Sequencing Batch Reactor (P-SBR). The pulsed flow is generated by a diaphragm reciprocating pump that recycles the effluent being treated. The objective of the present experiment was to perform a preliminary feasibility study of the operation of the system to treat an effluent with a COD near 1000 $mg.l^{-1}$, which may be considered by the anaerobic literature as a low strength wastewater, at a working temperature of 22°C. A first appraisal of the solid-liquid contact and mixing conditions in the reactor was also performed. Furthermore, because of the singular operation characteristics of the SBR, where a fraction of the reactor volume is frequently renewed, it was decided to assess if this effect could promote the development of an oxidation status inadequate for methanogenic bacteria.

MATERIALS AND METHODS

A diagram of the bench scale P-SBR system is depicted in Figure 1.



Captions:
p1 - influent in *(peristaltic pump)*
p2 - effluent out *(peristaltic pump)*
b1 - pulsator unit *(diaphragm pump)*
C - control system
max - maximum liquid level
min - minimum liquid level
ref - reference probe
R - recirculation line
T - thermo-recirculation pump *(water-jacket)*
liquid line: ——
on/off pump control line: ----
level sensor line:

Fig 1. Diagram of the experimental apparatus.

The reactor was made of acrylic glass, with a working volume of 1200 ml and an internal diameter of 52 mm. The pulse unit was a diaphragm pump, a type of pump belonging to the family of reciprocating volumetric pumps. Electrical or air powered diaphragm pumps generate volume and a pulsed flow practically independent of the discharge pressure. The fact that these pumps are amenable to flows with suspended solids and potentially corrosive environmental conditions (e.g. in sulphate wastewaters) is another favourable characteristic. The pump operates during the batch reaction time, recirculating the effluent from an intake below the liquid surface and injecting it upwards from the bottom of the reactor. In the present experiment an Astral electro-pump was used at a swept volume of 2 ml and 20 strokes per minute (spm) with an average flow rate of 2.4 $l.h^{-1}$.

The reactor was equipped with an electromechanical On/Off threshold control to execute the closed-loop operation. Two Watson Marlow-101 peristaltic pumps performed the substrate feeding and drainage functions. Both pumps were plugged to a liquid level relay, Megal 21 RN and a reference probe. At the reaction phase the reciprocating pump operated timed by a relay Mega 25 RT. Settling time was set by a relay Mega 14 RT. Temperature control at 22°C was provided by a water jacket and a Lauda T thermorecirculation pump.

The biomass inoculum was composed of anaerobic aggregates with 35.1 $kgVS.m^{-3}$ previously formed in a UASB reactor fed with a low strength wastewater. Scanning electron microscopy pictures show filamentous-like bacteria that resemble acetotrophic *Methanotrix* spp. The substrate was prepared to have a COD near 1000 $mg.l^{-1}$, being 10% glucose and 90% a mixture of acetic, propionic and butyric acids, in a proportion of 2:1:1. This substrate was supplemented with a solution containing macro and micronutrients, at a ratio of 2 ml and 0.03 ml per litre of substrate. The macronutrients solution, of substrate, was as follows, in $mg.ml^{-1}$: NH_4Cl: 174, KH_2PO_4: 28.3, $(NH_4)_2SO_4$: 28.3, $MgCl_2$: 25, KCl: 45, yeast extract: 3. The micronutrients solution, in $mg.ml^{-1}$: $FeCl_2.6H_2O$: 2, H_3BO_3: 0.05, $ZnCl_2$: 0.05, $CuCl_2.2H_2O$: 0.038, $MnCl_2.4H_2O$: 0.5, $(NH_4)_6Mo7O_2.4H_2O$: 0.05, $AlCl_3$: 0.09, $CoCl_2.6H_2O$: 2, $NiCl_2.6H_2O$: 0.092, $Na_2SeO_3.5H_2O$: 0.164, EDTA: 1. The substrate was previously neutralised with NaOH until a pH near 7.

The Chemical Oxygen Demand (COD) and volatile solids (VS) concentration were determined according to Standard Methods, 1985. Oxidation-reduction potential (ORP) was measured in situ with an Ingold combined electrode - platinium ring connected to a WTW meter, pH 95. The mixing intensity was assessed by a tracer test. A lithium chloride solution (2.5 ml of 20 $g.l^{-1}$) was injected in the effluent recirculation line, just near the bottom of the reactor and the liquid conductance (C) was measured with a WTW conductivity meter until equilibrium tracer concentration (C_E) was attained. The conductivity probe was positioned near the surface, at the recirculation intake. At the time of the experiment, it was just possible to perform one tracer test with the empty reactor.

A typical experimental loop routine of the reactor operation is depicted in the following scheme, indicating phase name and cycle duration:

Fill	React	Settle	Draw
18 minutes	6 or 5 hours	10 minutes	5 minutes

The reaction step lasts 6 hours during the first week and 5 hours during the remaining experimental time.

RESULTS AND DISCUSSION

Each liquid stroke delivered by the reciprocating pump had an obvious turbulent effect in the biomass bed of the reactor. The whole sludge bed was observed to mix well under the induced pressure flow and the liquid-solid contact seemed to be satisfactory, also minimising possible liquid film mass transfer resistance. This observation may be normalised considering the ratio of the swept and reactor volumes, which was 1.8‰. Figure 2 shows the normalised liquid conductivity measurements as a function of the time after the injection of the tracer in the P-SBR.

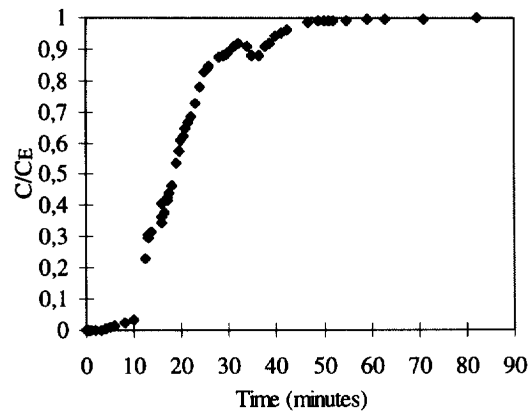


Fig. 2. Plot of experimental C/C_E values versus time.

The tracer curve in Figure 2 clearly suggests an intermediate mixing flow pattern in the reactor, as the nominal liquid circulation time was 30 minutes. At this time, a mixing intensity of 90% was attained. This means that the time to reach the equilibrium tracer concentration was just slightly higher than the liquid circulation time. Therefore, the possibility of a significant presence of stagnant zones, with rather slow mass transfer between flowing and non-flowing zones, seems to be narrow. Possibly, the pump flow rate could be set at a lower level without any significant reduction of the removal efficiency. This possibility is attractive since energy consumption of diaphragm pumps are proportional to the stroke rate.

The Figure 3 displays the continuous ORP values measured during the reaction phase. The pH during this experiment was 7.5 and the temperature was 22°C.

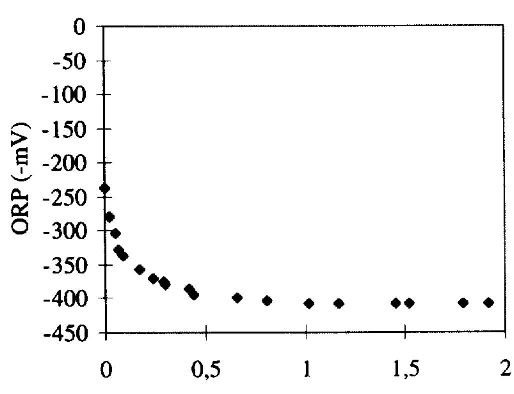


Fig. 3. Time evolution of ORP profile during initial period of reaction phase.

The ORP is a measure of electron activity during oxidation-reduction reactions. Undoubtedly, the progress curve in Figure 3 demonstrates a reduction of electron acceptors in the media. The curve indicates that soon after the beginning of the reaction an anaerobic environment is reached. In the conditions of the experiment, a reduced system near -400 mV was attained in half an hour. Several steady-state ORP values are reported in the case of methanogenic reactors by Harper and Pohland (1986), but all are also below -370 mV. Oxygen was easily scavenged from the system, eventually with a contribution of facultative bacteria. Therefore, it can be concluded that no oxygen inhibition occurred as a result of the fed-batch fill and draw operation, in spite of the fact that the top of the reactor was always uncovered. Kato *et al.* (1994), found a high oxygen tolerance in granular sludges. Furthermore, an operating mode allowing the existence of facultative and anaerobic cultures may have some potential for combined processes for removal of organic matter and nutrients, even allowing the possibility of air supply if necessary, as suggested by Kato *et al.* (1994). The prospects that SBR technique offers for such systems are fair. In order to complement the rather few stability indicators available for on-line anaerobic reactors control (Weiland and Rozzi, 1992), the potential of ORP measurements merit further research in anaerobic SBR.

Influent and effluent COD measurements during the time course of the experiment with the P-SBR are presented in Figure 4. COD values were measured in the feed reservoir and after the reaction step.

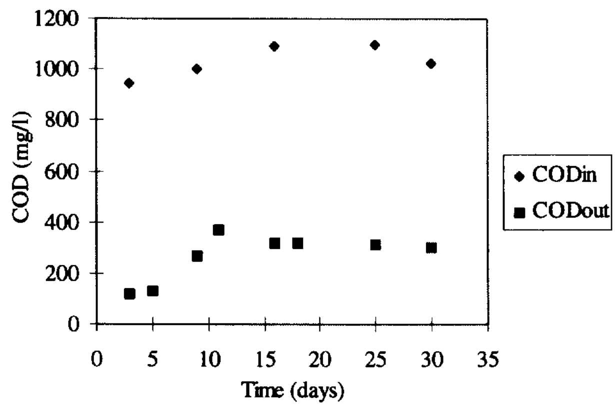


Fig. 4. COD values at influent and effluent during experimental time.

The results presented in Figure 4 show an overall COD removal efficiency between 60-70%. As could be expected, the removal efficiency was slightly higher at a reaction time of 6 hours (first week) than when it was changed to 5 hours. The applied organic load varied between 4 - 5 kg COD.m^{-3}.day^{-1}, within the limits of the recommended value for soluble substrates at 20°C by Lettinga and Hulshoff Pol (1992). The average activity was 0.5 kg COD$_r$.m^{-3}day^{-1}, a value in the low range of the reported data for methanogenic activity in high rate reactors (Field *et al.*, 1988). This rate can be the result of the sub-optimal working temperature, 22°C, lower than the optimum for methanogenesis, 35°C. Temperature factor is indeed important for anaerobic processes determining the advocated organic loads. The assurance of a minimum temperature of 15°C is advisable (Vieira and Garcia Jr, 1992). A rate inhibition induced by a possible high initial VFA concentration is not very likely, due to the minimum working pH 7. Substrate toxicity is related to the non-unionised forms and a major fraction of VFA is dissociated at the actual pH in the reactor (Andrews, 1968).

Finally, regarding the settling phase, it should be noted that 10 minutes was largely in excess for the sedimentation of biomass in the bench-scale reactor, due to the high terminal velocity of the aggregates. However, such settling time could be the safe factor for full-scale granular reactors and yet representing a time gain in the equalisation and overall operation time requirements. A careful control should be made in order to avoid the discharge of solids with low settling velocities, which would decrease effluent quality. Conversely, if the purpose is to select aggregate forming bacteria, the settling time should be adjusted to wash-out dispersed biomass, like in a typical granulation process (Lettinga and Hulshoff Pol, 1992).

CONCLUSIONS

From the results obtained in the present research, it can be concluded that the Pulsed - Sequencing Batch Reactor (P-SBR) is a feasible system for the treatment of a low strength soluble wastewater with a COD of approximately 1000 mg.l^{-1}, at a sub-optimal temperature, 22°C. Using anaerobic biomass aggregates, an overall COD removal rounding 60-70% was attained at organic loads of 4 - 5 kg $COD.m^{-3}.day^{-1}$. A pressure pulse induced by a diaphragm pump was a convenient technique to generate an adequate liquid-solid contact, in order to overcome the low gas production or the absence of any other mixing mechanism. A swept/reactor volume ratio of 1.8 ‰ and a stroke rate of 20 spm seemed to be sufficient for the proposed objectives, minimising possible stagnant zones in the reactor or liquid film mass transfer resistance.

ACKNOWLEDGEMENTS

This work was sponsored by the program PRAXIS XXI, through Project 2/201/BIO/37/94. The authors are very grateful to Prof. J. Teixeira and A. Vicente, University of Minho, for the utilisation of the ORP probe.

REFERENCES

Andrews, J.F. (1968). A dynamic model of the anaerobic digestion process. In: *Proceedings of 23th Industrial Waste Conference*, Purdue University, Lafayette, 285-400.

A.P.H.A., A.W.W.A., W.P.C.F. (1985). *Standard Methods for the Examination of Water and Wastewater.* 16th edition, APHA (ed.), Washington DC, U.S.A.

Draaijer, H., Maas, J.A., Schaapman, J., Khan, A. (1992). Perfomance of the 5 MLG UASB reactor for sewage treatment in Kampur, India. *Water Science and Technology*, **25**, 7, 123-134.

Field, J., Alvarez, R.S., Lettinga, G. (1988). Ensayos anaerobios. In: *Actas del 4º Seminario Depuration Anaerobia de Aguas Residuales*. Polanco, F., Garcia, P., and Hernando, S., (Ed). Universidad de Valladolid, 52-81.

Harper, S.R., Pohland, F.G. (1986). Recent developments in hydrogen management during anaerobic biological wastewater treatment. *Biotechnology and Bioengineering*, **28**, 585-602.

Irvine, R. L., Fox, T.P., Richter, R.O. (1977). Investigation of fill and batch period of sequencing batch reactor. *Water Research*, **11**, 713-717.

Lettinga, G. and Hulshoff Pol, L.W. (1992). UASB-process design for various types of wastewaters. *Water Science and Technology*, **24**, 8, 87-108.

Kato, M.T., Field, J.A., Versteeg, P. and Lettinga, G. (1994). Feasibility of expanded granular sludge bed reactors for the anaerobic treatment of low strength soluble wastewaters. *Biotechnology and Bioengineering*, **44**, 4, 469-480.

Pfeiffer, W., Temper, U., Steiner, A., Carozzi, A. and von Mucke, J. (1986). Anaerobic wastewater treatment - results of a literature review. In: *Proc. of the Water Treatment Conference, Anaerobic Treatment a Grown-up Technology, AQUATECH'86*, Amsterdam, The Netherlands. 219-231.

Schellinkhout, A., Collazos, C.J. (1992). Full scale application of the UASB technology for sewage treatment. *Water Science and Technology*, **25**, 7, 159-166.

Stadlbauer, E. A., Achenbach, R., Döll, D., Jehle, B., Küfner, B., Oey, L., Quurck, J. (1992). Design and perfomance of a pulsed anaerobic digesters. *Water Science and Technology*, **25**, 7, 351-360.

Sung, S., Dague, R. (1992). Fundamental principles of the anaerobic sequencing batch reactor process. In: *Proceedings of 47th Purdue Industrial Waste Conference*, Lewis Publishers, Inc., Chelsea, Michigan, 393-407.

Weiland, P., Rozzi, A. (1992). The start-up, operation and monitoring of high-rate anaerobic treatment systems: Discusser's report. *Water Science and Technology*, **24**, 8, 257-278.

Vieira, S. M. M., Garcia Jr, A. D. (1992). Sewage treatment by UASB reactor. Operation results and recommendations for design and utilization. *Water Science and Technology*, **25**, 7, 143-158.