

IASB-Inverted Anaerobic Sludge Blanket reactor: background, history and development

M. Picavet^{*,**}, M. Alves^{*,**}

* – IBB, Institute for Biotechnology and Bioengineering, Centre of Biological Engineering, University of Minho, Braga, Portugal

** – Ambisys SA, Rua Maria Paz Varzim, 126, Póvoa de Varzim, Portugal

Corresponding Author: merijn.picavet@ambisys.pt

Abstract

Existing high rate anaerobic technology such as UASB, EGSB and IC reactors based on granular sludge is not robust when applied to industrial effluents with high lipids content. After discovering the potential of converting fat and long chain fatty acids to methane, the development of a compact high rate anaerobic reactor technology for the treatment of effluents of high lipid content was pursued. In this paper the fundamentals of anaerobic LCFA degradation are revised. The basic principles of the IASB technology are described and results of a pilot plant treating a slaughterhouse effluent are presented. An organic loading rate of 16 kg COD/m³.day was applied being 63% of FOG. Effluent VSS were around 500 mg/L COD, removal efficiency was consistently above 80% and excessive LCFA accumulation was prevented (<1 g COD-LCFA/gTS). The start-up of the first full scale reference of the IASB reactor located in a fish canning factory (A Poveira, Portugal) is described.

Keywords: Long Chain Fatty Acids; Slaughterhouse wastewater, anaerobic reactor technology

INTRODUCTION

High-rate anaerobic technology is widely accepted for industrial wastewater containing readily degradable organic pollutants such as volatile fatty acids and carbohydrates. Lipids, either fat oil or grease (FOG) do not belong to this group. FOG hydrolysis results in the production of long chain fatty acids (LCFA) which have been, for several years, considered extremely toxic to anaerobic bacteria and a nuisance because they induce floatation of biomass, thus disrupting conventional anaerobic treatment systems that are based on biomass sedimentation (granulation). Therefore, FOG is normally removed from wastewater prior to anaerobic treatment using e.g. dissolved air floatation. In this work we present the road map of fundamental research that supported the development of the Inverted Anaerobic Sludge Blanket (IASB) reactor [1] and the main operational characteristics of this novel reactor.

FUNDAMENTALS

The history of the IASB reactor started with the realization that anaerobic sludge could produce methane very efficiently (no lag phase, rates between 200 and 600 mg COD-CH₄/gVS.day) in batch vials from LCFA that remained adsorbed to the cells of anaerobic sludge sampled from a continuous up-flow reactor fed with an oleate (C18:1) based effluent [2,3]. The evidence of a reversible physical inhibition due to mass transfer limitations [4], the evidence that methanogens endure high loads of LCFA [5], the understanding of the biochemical pathways involved and the microbial composition of saturated and unsaturated LCFA degrading cultures [6], and the need for a sequencing feeding during the start-up [7], dictated the design principles of a reactor capable of high-rate anaerobic treatment of LCFA containing wastewater.

1. Maximise the contact area between biomass and LCFA as to optimize LCFA adsorption, since LCFA adsorption forms the first step in effective LCFA conversion to biogas.

2. Use floatation as the primary biomass retention technique, since LCFA induced floatation is currently the main reason why LCFA are removed prior to anaerobic treatment.

These two principles imply that conventional primary biomass retention techniques such as granulation or biomass fixation cannot be applied. However, a settling step is still needed, because sludge settles well again after effective LCFA conversion. This settled sludge can subsequently be intimately contacted with LCFA containing wastewater as to maximise adsorption. Thus, a sludge recycle loop should be present over the reactor. This loop could further provide the mild shear stress needed to maximise the sludge surface area. Additionally, it provides the means to control mixing intensity inside the reactor and reduce possible mass transfer limitations even further. Summarising, an effective reactor would need to provide the following:

1. Primary biomass retention through floatation.
2. Secondary biomass retention through settling.
3. Contact area maximisation using mild shear stress.
4. Mass transfer maximisation by adequately controlling mixing intensity.
5. LCFA adsorption induction through intimate contact between influent and recycled settled sludge.

This resulted in the Inverted Anaerobic Sludge Blanket (IASB) reactor for the high rate anaerobic treatment of (waste)waters with relatively high concentrations of lipidic compounds (Alves et al., 2007).

PILOT TESTING

The reactor concept was first tested at lab scale and then taken to pilot scale. A demonstration plant was operated at a slaughterhouse (Matadouro do Barroso e Alto Tâmega, Portugal) during 1 year and included a 1 m³ reactor (Figure 1).



Figure 1 – Pilot-scale reactor located in Montalegre, North of Portugal.

The raw effluent composition fed showed to be highly variable (Table 1), but gave the chance to test the technology in a worst case scenario context. An average COD removal efficiency of $83\pm 7\%$ for total COD and 92.3 ± 3 for soluble+colloidal COD was maintained in spite of the variability. The organic loading rate during the pilot trial achieved a value of $16 \text{ kgCOD/m}^3\cdot\text{day}$ and the fat removal efficiency was consistently above 85% for loading rate above $10 \text{ kg COD/m}^3\cdot\text{day}$.

Table 1 – Chemical characterization of the slaughterhouse effluent

	Average±standard deviation	range
Total COD, g/L	10.7±5.6 (n=110)	[4.1-33.1]
Soluble COD, g/L	4.1±2.1 (n=110)	[1.1-12.9]
Total Nitrogen, mgN-NH4/L	694±429 (n=41)	[111-2554]
Soluble Nitrogen, mgN-NH4/L	131±110 (n=41)	[23-457]
Sulphate, mg S-SO ₄ ²⁻ /L	130±105 (n=25)	[11-554]
pH	6.6 ±0.4 (n= 165)	5.9-8.6
HRT	variable	[0.6-10]

The accumulation of LCFA in the reaction-flotation section increased up 1.1 g COD-LCFA/gTS and decreased considerably, even when the fat loading rate achieved 12 kg COD-Fat/m³.d. The critical value previously determined of 1 g COD-LCFA/gTS [8] was exceeded only sporadically.

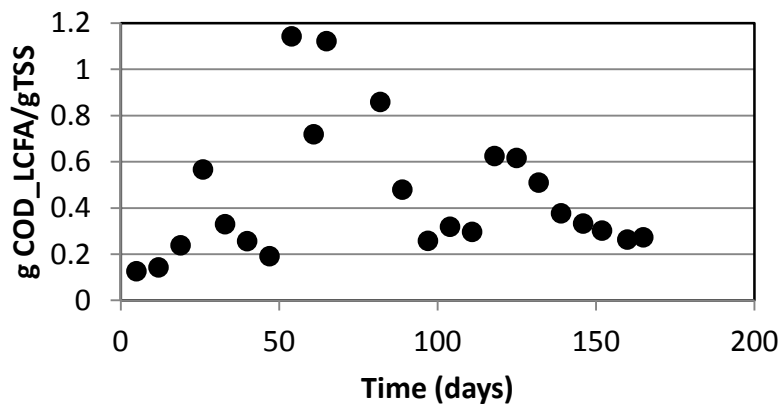


Figure 2 - Accumulation of total LCFA in the floating sludge (reaction section)

These results demonstrate the robustness of the technology and at the same time uncovered items that could be improved. All data generated were enough to proceed to successful scale-up to industrial size.

SCALE-UP AND INDUSTRIAL DEVELOPMENT

The pilot reactor was designed to demonstrate the technology. The design as such was not adequate for industrial scale application and therefore it had to be rethought to include all the specific design features, while minimizing construction costs. Specifically the inclusion of a tilted plate separator (TPS) in the reactor was challenging. The solution was found in a modular TPS that could be easily reproduced and installed inside cylindrical reactors of different kinds of material. Maximum hydraulic load per module was set at 20 m³/h. Reactor sizing was done by applying a mean organic loading rate of 10 kg COD/m³/day. Actual organic loading rate applied will depend on wastewater complexity. Up to 15 kg COD/m³/day can be dealt with.

Taking these parameters into account, a 100 m³ reactor was designed and has recently been installed at a fish processing industry (a Poveira) in northern Portugal (Figure 3). The plant construction was co-funded by the European Commission through the Eco-Innovation program BioFatrecovey. The reactor was completely constructed in high density polyethylene (HDPE) due to its smoothness, thus preventing fat deposition as much as possible. It is equipped with specifically design injectors to mix up the floating fat layer. Furthermore, several spray heads are installed to counteract foam formation. Currently, the reactor is being started up in batch. It will be in full operation in the beginning of 2013.



Figure 3 – Full-scale reactor located at A Poveira, Póvoa de Varzim, Portugal.

With the full-scale installation, the next step was taken in coming to fully implemented industrial application of the IASB reactor. It will give the opportunity scale up the reactor to bigger sizes using the same TPS modules and injectors.

CONCLUSIONS

- The IASB reactor has proven to remove efficiently fat from an effluent with high lipids content up to 63% of the total organic loading rate.
- Fat removal efficiencies higher than 85% were achieved for organic loading rate between 10 and 16 kg COD/m³.d, (63% as animal fat).
- The effluent VSS concentration did not change significantly when the fat loading rate increased
- Although sludge flotation was promoted in the top of the reactor the mild shear conditions applied in the reaction section, promoted an efficient LCFA degradation and no excessive LCFA accumulation was observed..

REFERENCES

- [1] WO 2007058557 - Novel anaerobic reactor for the removal of long chain fatty acids from fat containing wastewater.(Alves M.M., Picavet, M.A., Pereira, M.A., Cavaleiro, A.J., Sousa, D.Z).
- [2] Alves, M.M., Mota Vieira, J.A., Álvares Pereira, R.M., Pereira, M.A., Mota, M. (2001) Effects of Lipids and oleic Acid on Biomass Development in Anaerobic Fixed Bed Reactors. Part II: Oleic acid toxicity and biodegradability. *Water Research* 35:1, 264-270.
- [3] Pereira M.A., Pires O.C., Mota M., Alves, M.M. (2002) Anaerobic degradation of oleic acid by suspended and granular sludge: identification of palmitate as a key intermediate. *Wat. Sci. Tech.*, 45, 139-144.
- [4] Pereira, M.A., Pires, O.C., Mota, M., Alves, M.M. (2005) Anaerobic biodegradation of oleic and palmitic acids: evidence of mass transfer limitations caused by the accumulation of LCFA onto the anaerobic sludge. *Biotechnol Bioeng.* 92 (1), 15-23
- [5] Salvador AF, Cavaleiro, AJ, Sousa DZ, Alves MM, Pereira, MA. (2012) Endurance of methanogenic archaea in anaerobic bioreactors treating oleate-based wastewater. *Applied Microbiology and Biotechnology* in press.
- [6] Sousa, D.Z., Smidt, H., Alves, M.M., Stams, A.J.M. (2009) Ecophysiology of syntrophic communities that degrade saturated and unsaturated long-chain fatty acids. *FEMS microbiology ecology*, 68, 257-272
- [7] Cavaleiro, A.J., Alves, J.I., Alves, M.M. (2009) Continuous high rate anaerobic treatment of oleic acid based wastewater is possible applying a step feeding start-up. *Environmental Science and Technology* 43(8), 2931-2936.
- [8] Pereira M.A., Sousa D.Z., Mota M., Alves M.M. (2004) Mineralization of LCFA associated to anaerobic sludge: kinetics, transport limitations, enhancement of methanogenic activity and effect of VFA. *Biotechnol Bioeng.* 88(4), 502-511.