A compact high-rate anaerobic reactor configuration for the treatment of effluents with high lipid content

M. Picavet[1,2], M. Alves[1,2]

1 – IBB, Institute for Biotechnology and Bioengineering, Centre of Biological Engineering, University of Minho, Braga, Portugal
2 – 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 basic principles of the IASB technology (patented) 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 fat. 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) in the reaction section of the IASB reactor.

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

Introduction

High-rate anaerobic technology is an accepted technology for industrial wastewater treatment. More than 2,000 full-scale installations are running worldwide (Van Lier, 2007) and mainly treat wastewaters containing readily degradable organic pollutants such as volatile fatty acids and carbohydrates. Lipids do not belong to this group, since their hydrolysis results in the production of long chain fatty acids (LCFA). Until recently these were considered toxic to anaerobic bacteria and a nuisance because they induce floatation of biomass (Hwu, 1997). Since the success of conventional anaerobic treatment systems is based on optimisation of biomass sedimentation, floatation leads to washout and subsequent process disruption. Therefore, lipids are normally removed from wastewater prior to anaerobic treatment using e.g. dissolved air floatation.

Pereira et al. (2002) showed that lipids are not toxic and can be converted to biogas. As to prevent washout induced by LCFA adsorption, a sequential process including at least a feeding and reaction phase was proposed as the preferred technology for anaerobic LCFA removal from wastewater (Pereira et al., 2005). It was further postulated that the specific contact area between bacteria and LCFA should be maximised as to maximise LCFA adsorption and minimise mass transfer limitations. The sequential process was applied at lab scale by Cavaleiro et al. (2009). Volumetric loading rates up to 20 kg COD/m3/day were achieved on lab scale with 80% conversion to methane, with a synthetic effluent made by 50% COD as oleic acid. Furthermore, the feeding phase could be prolonged with every cycle, showing that a continuous process for LCFA treatment should be possible. From the current problems encountered at industrial scale with LCFA and the research results from Pereira et al. (2002-2005) two main principles may be postulated for the design of a reactor capable of high-rate anaerobic treatment of LCFA containing wastewater. These form the base of the proposed reactor concept:

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. A critical feature of this reactor is to limit the amount of LCFA accumulated onto de cells, since this causes problems of mass transfer (Pereira et al., 2005). According to the kinetics determined by Pereira et al. (2004), the optimal amount of COD-LCFA that should be accumulated onto the cells in order to maximize the LCFA-to-methane conversion rate was about 1 g COD-LCFA/g TS. This value was however observed in batch assays, in specific and more defined conditions than the ones prevailing in a continuous reactor fed with a real wastewater. Furthermore Pereira et al. (2003) also determined that 1 g COD-LCFA/g TS had already a negative effect in the measured specific methanogenic activity.

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 a novel patented reactor concept (Alves et al., 2007). The invention is an apparatus specifically designed for the high rate anaerobic treatment of (waste)waters with relatively high concentrations of lipidic compounds, referred to as the Inverted Anaerobic Sludge Blanket (IASB) reactor. Contrary to conventional anaerobic reactors, it avoids the need of sludge with good settling properties and exploits the problem of sludge flotation due to long chain fatty acid (LCFA) or biogas adsorption onto the sludge and/or biogas encapsulation by the sludge. Furthermore, it provides an increased specific sludge surface area for better LCFA degradation. It is fed from the top and is equipped with a separation step at the bottom. Reactor contents are thoroughly mixed by the novel combined action of a gas lift loop and a liquid recycle over the reactor. The reactor can be operated in continuous and sequential mode. Although it is specifically designed for lipid degradation, its application is not limited to this. Figure 1 shows a schematic representation of the reactor concept.

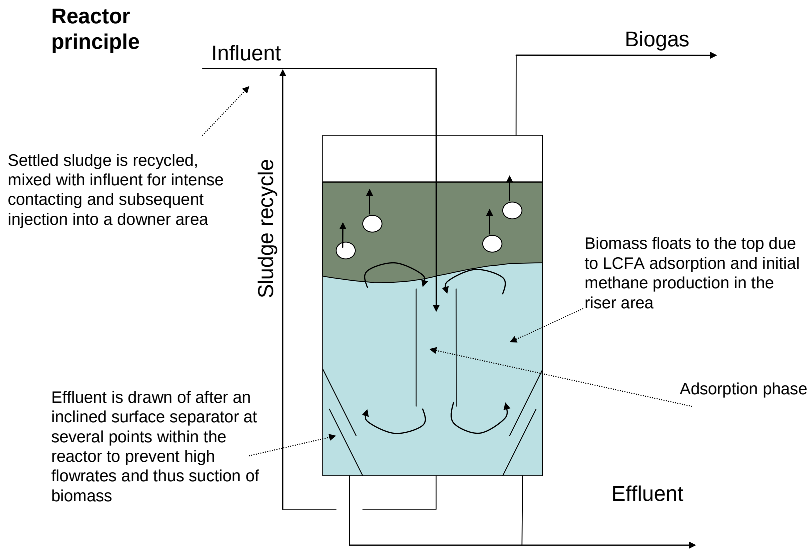

Figure 1. IASB Reactor concept.

The main results obtained in the proof of concept of the IASB reactor are presented in this paper.

Materials and methods

Experimental set-up and routine analysis

The pilot scale reactor had a total volume of 1032 L, was constructed in stainless steel and was composed of three parts: (i) reaction, (ii) separation and (iii) effluent discharge. The operating temperature was set at 37 C. Figure 2 presents the pilot scale reactor "on site", located on the "Matadouro do Barroso e Alto Tâmega", Montalegre, north of Portugal.

Figure 2 – Pilot-scale reactor located in Montalegre, Nord of Portugal.

The raw effluent composition was highly variable (Table 1)

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

Routine analysis was performed according to Standard Methods (VSS, TSS) and according to adapted Hach Lange methods (COD, P, N, S). Long Chain Fatty Acids were quantified by the method described by Neves et al., 2009.

Reactor operation was divided in two periods. In the first period, the raw wastewater (composition in Table 1) was fed for a period of about 100 days. The ratio between fat loading rate and total organic loading rate was very variable between 0,6 and 45% in this first operation period. In the operation period II that lasted 80 days, besides feeding the wastewater, animal fat was periodically introduced in the reactor, in order to increase the fat loading rate. Figure 3 represents the relationship between the total organic load and the organic load as fat fed to the reactor, which accounted, on average, to 63% of the total organic loading rate.

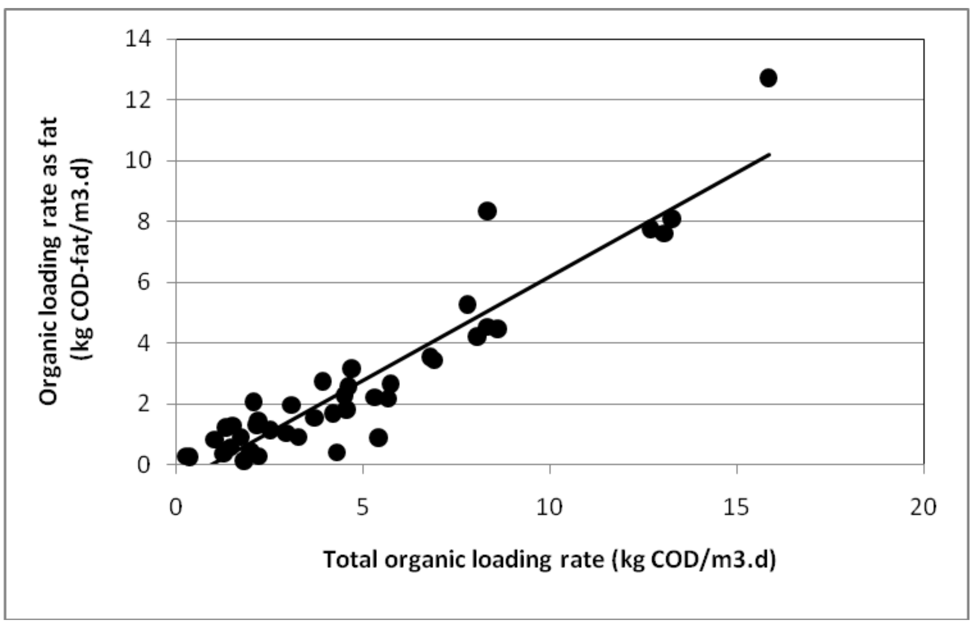

Figure 3 – Relationship between the total and organic loading rate (as fat) fed to the reactor, during the operation period II.

Results and discussion

The COD removal efficiency of the IASB reactor during the period I, was variable with an average of 83±7% for total COD and 92.3±3 for soluble+colloidal COD. The organic loading rate was relatively low at 1.5±1.0 kgCOD/m3.d Figure 4 represents the influent and effluent COD concentration during Period I.

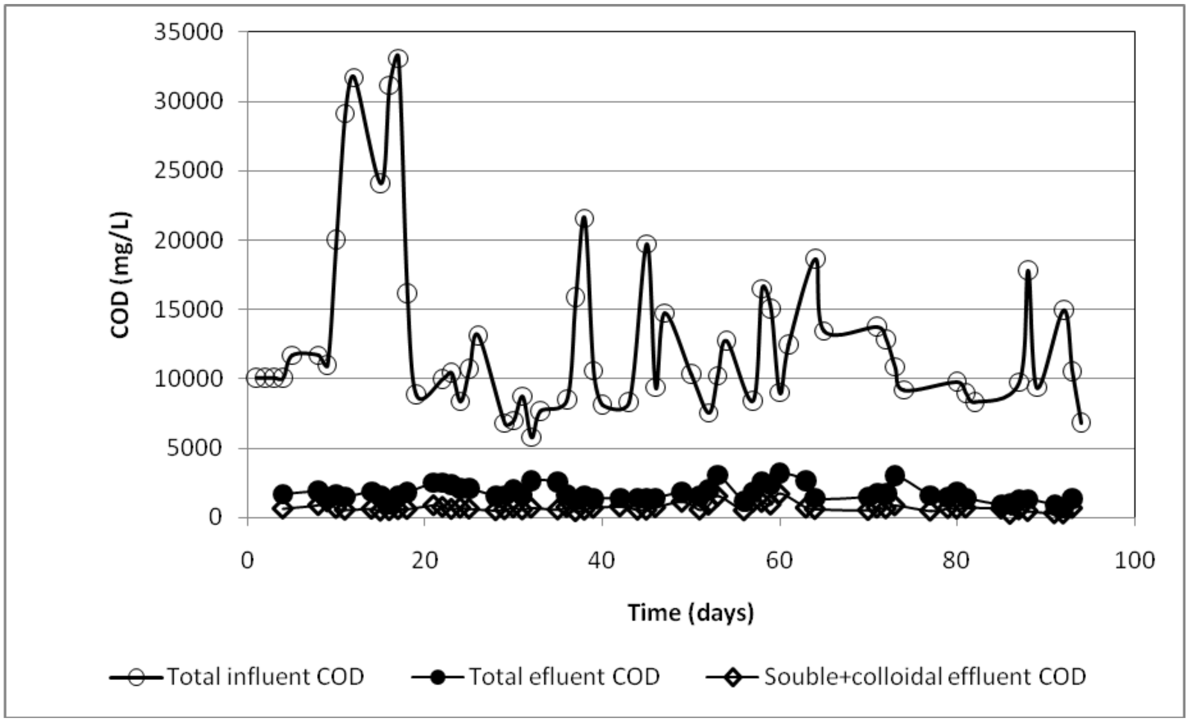

Figure 4 – Influent, total and soluble+colloidal effluent COD during operation Period I.

During the period II, the organic loading rate achieved a value of 16 kgCOD/m^3.day and the fat removal efficiency was consistently above 85% for loading rate above 10 kg COD/m^3.day (Figure 5).

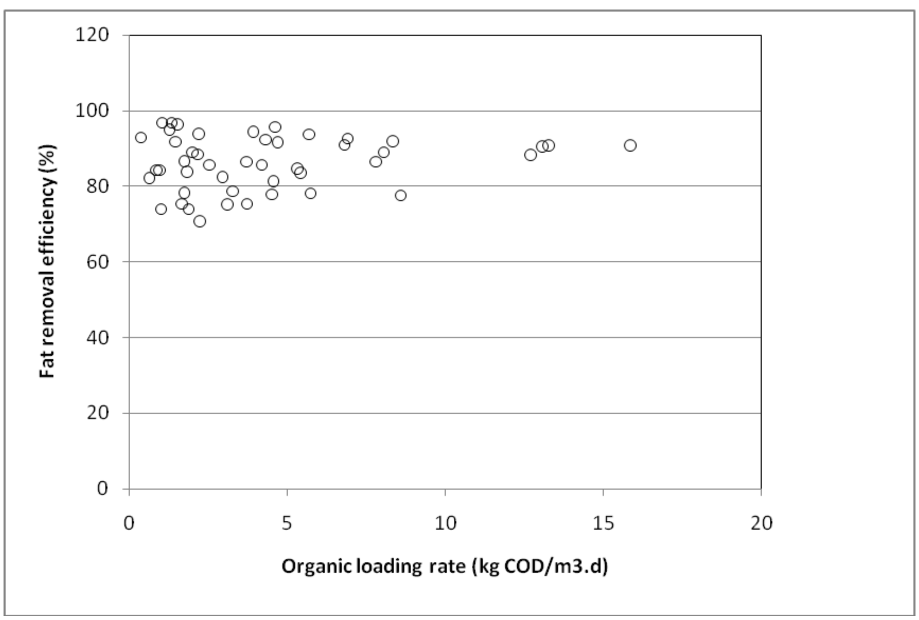

Figure 5 – Influence of the organic loading rate on the fat removal efficiency, during period II.

Passeggi et al., 2009 demonstrated the effectiveness of an anaerobic reactor fed with a dairy industrial wastewater that was constituted by two UASB reactors (in parallel), an external sludge flotation tank and an external settler. The advantage of the present rector concept as compared to the one described by this author is its compactness.

The accumulation of LCFA in the reaction-flotation section was determined (Figure 6). Interestingly in the Operation Period II the amount of LCFA accumulated decreased considerably, even when the fat loading arte increased up to 12 kg COD-Fat/m^3.d. The critical value previously determined of 1 g COD-LCFA/gTS was exceeded only sporadically in the Period I. In Period II a maximum of 0,6 COD-LCFA/gTS was not exceeded.

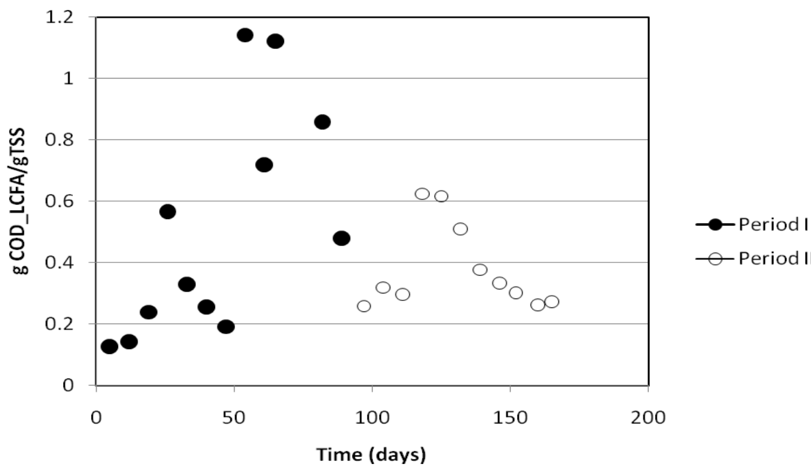

Figure 6 – Accumulation of total LCFA in the floting sludge (reaction section)

The average effluent VSS concentration in the first and second operation period respectively were 526±148 and 347±123 mg/L.

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/m^3.d, (63% as animal fat).
- The effluent VSS concentration did not change significantly when the fat loading rate increased in the Operation Period II.
- 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.

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