Experiences with anaerobic treatment of fat-containing food waste liquids: two full scale studies with a novel anaerobic flotation reactor

C.T.M.J. Frijters*[1], T. Jorna*, G. Hesselink*, J. Kruit*, D. van Schaick**, R. van der Arend***

** PAQUES BV, T. de Boerstraat 24, 8561 EL, Balk, the Netherlands*
***ITC Holland Transport BV, Vorstengrafdonk 71, 5342 LW Oss, the Netherlands*
****Ben&Jerry's, Reggeweg 15, 7447 AN Hellendoorn, the Netherlands*

Abstract
Fat-containing food waste can be effectively treated in a new type of reactor, the so-called BIOPAQ-Anaerobic Flotation Reactor or BIOPAQ®AFR. In the reactor a flotation unit is integrated to retain the sludge. In this study results from two plants with a 500 m^3-AFR are presented. Fat and oil were removed over 99 % in one reactor which was fed with water that derived from different food liquid streams; the COD was removed for over 90%. When the last solids were removed from the effluent with a tilted plate settler, 98% removal was attained. The concentrations of extractable hydrolysed and non-hydrolysed fats in the effluent were less than 40 mg/l. The variations in types and concentrations of fats and oil in the influent did not disturb the system. Only extreme high concentrations of fats could disturb the system, but the inhibition was reversible. Fat accumulated in the sludge up to 35 % of COD. For higher values, the COD removal decreased. In the reactor treating water from an ice-cream factory, the COD was removed for 90 %. Fats in the influent made up for approximately 40 % of the COD in the influent. At a VLR varying from 1-8 kg COD/m^3/d biogas was produced at a specific gas production of 0.6 m^3/kg COD–removed. It can be concluded that the fats and oil present in the food wastewater were effectively converted. The mixing and flotation of the flocculent biomass with biogas in the AFR system seems to be very successful in attaining high conversion rates of fats and oil.

Keywords
Anaerobic flotation reactor; dairy; digestion; fat; flotation; food waste water; ice-cream waste; LCFA; oil.

INTRODUCTION

Waste water produced by food industry often contains besides carbohydrates and proteins, energy-rich oil and fats. The compounds are very suitable for anaerobic bacterial conversion into biogas. The types of anaerobic reactors used for that purpose are high rate reactors for more diluted streams (up to 30 g/l of COD), or a CSTR for more concentrated wastewaters (from 70 g/l of COD). **G**ranular sludge systems do not seem to be appropriate because granules can be trapped by the fats and oil and as a result may float out of the reactor (Hwu et al., 1998). On the other hand because CSTR technology is hydraulically designed (no sludge is retained), large CSTR volumes are required to treat these kinds of streams. A new type of reactor, the so-called BIOPAQ®-Anaerobic Flotation Reactor or BIOPAQ®AFR (PCT/NL02-26-03-02, Vellinga and Mulder, 2002), is especially designed to treat wastewater streams containing fats and oil. In the reactor digestion is combined with an integrated flotation unit. The sludge is retained in the reactor up to concentrations of 15-30 g/l. These high concentrations allow the application of high volumetric loading rates (VLR): up to 9 kg of COD/m^3-reactor/d, with an HRT of 1.5-8 days. The SRT can be longer than 50 days. The flocculent sludge is floated with small biogas bubbles dissolved in effluent (the white water). Sludge on which fatty compounds are adsorbed will not be washed out like in granular sludge systems, but will be floated and retained in the system, as found in a former study with this system (Frijters et al., 2008). Comparing to other technologies like the combination

[1] Corresponding author: c.frijters@paques.nl

DAF+CSTR+EGSB, the AFR technology is besides the smaller food print cheaper in operation and chemical use (no polymer dosing). The power consumption of the different set-ups is comparable (Hülsen et al., 2010).
A pilot was successfully conducted with wastewater deriving from cleaning tanks that transport food liquids (ITC Holland Transport BV). A 500 m^3-prototype reactor was built at this company in November 2009. And in 2011 another full scale reactor was started, at the ice-cream producing company (Ben & Jerry's), after a 4-months pilot plant study. In this abstract the results of sludge retention and removal of organics, including fat and oil compounds of the prototype reactor treating the wastewater from the tank cleaning company, are presented. The results at the ice cream factory are only briefly presented; more results will be presented during the oral presentation.

MATERIALS AND METHODS

The reactor, the principle

The reactor system is described previously (Frijters et al., 2008).

Set-up

Prototype at the tank cleaning company:
The prototype of BIOPAQ®AFR was running from the end of 2009 at ITC Holland Transport BV. The reactor has a maximum water level of 13.5 m and a diameter of 6.8 m, corresponding with a maximum water volume of 490 m^3. The water is buffered in a 40-m^3 mixed buffer. The fats are skimmed and collected in a separate 20-m^3 mixed buffer. The fats can be fed to the reactor influent pipe by a controlled flow. The temperature in the reactor is approximately 35 °C, regulated by the heat-exchanger cooling the wastewater. The pH in the reactor is controlled with caustic at a minimum of 6.3. Urea and phosphoric acid are dosed in the influent pipe line. The biogas produced is used in a boiler to heat water for tank cleaning purposes.

Inoculum

For both reactors granular sludge deriving from brewery IC reactors was crushed and inoculated.

The wastewater

The wastewater from the tank cleaning company originates from a variety of food producing companies. The water composition varied largely: the COD varied between 3.6 g/l and 30 g/l with a average of 11.3 g/l of COD (4.3 g/l of COD filtered (12.000*g*). The fat-COD (ratio of fat:fat-COD is estimated to be 1:2.5), could make up over 30 % of the COD. If necessary the water (in the buffer up to 55 °C) is cooled in a heat-exchanger to a temperature of around 36°C. The pH is controlled by caustic dosing.

Measurements and analyses

The influent, the reactor content and the effluent were sampled daily for 5 days a week. The COD total and centrifuged (12,000*g*) and VFA were analysed in the samples with HACH method (Tiel, The Netherlands).

Figure 2: The BIOPAQ®AFR at ITC (left) and at Ben&Jerry's (right)

RESULTS AND DISCUSSION

Development of the system and improvements at the prototype AFR at ITC

At ITC the prototype AFR was developed and improved. A major improvement before March 2010 was achieved by fine tuning the flotation system (both technical and process technological): e.g. technical adaptation of nozzles, settings of flows towards and out the flotation system to improve thickening of the flotation. Data are shown from March 2010, when the installation was inoculated with anaerobic sludge.

(a) (b)

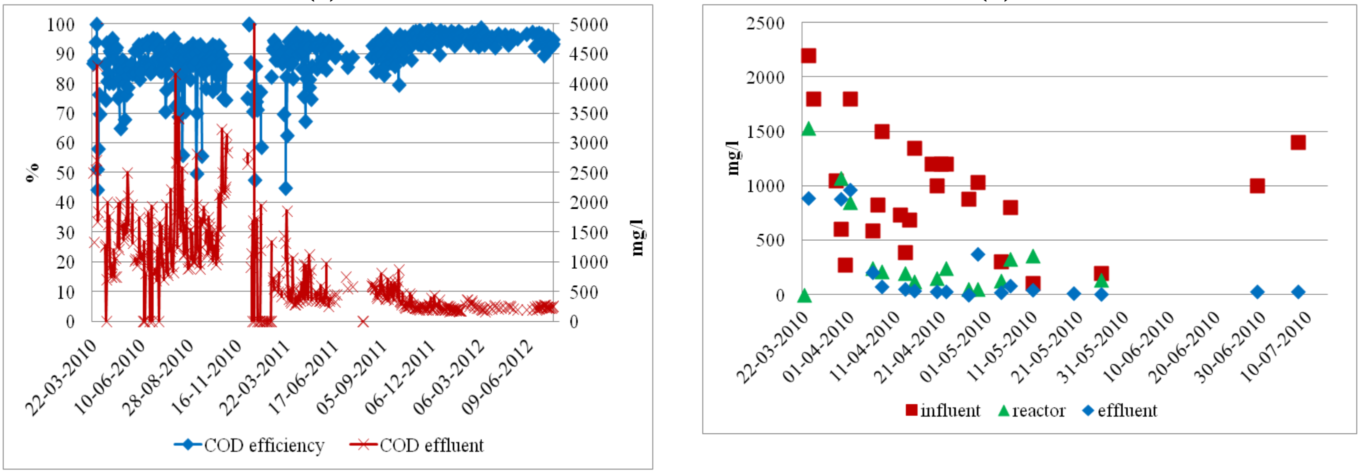

Figure 3: (a) COD removal efficiency and COD effluent. b) fat concentrations in the influent, sludge and effluent of the AFR at the tank cleaning company.

From the results can be concluded that the COD, including the high concentrations of fat, were largely removed (over 90 %). The removal efficiency COD was increased from 86 % to 90 % by stabilising the biogas feed to the white-water pump (January 2011). In October 2011 a tilted plate settler was installed to remove the last part of the COD, resulting in efficiencies over 98 %. Based on results of a pilot study at the same company (Frijters et al., 2008), the installation was designed for a removal of 8.4 kg COD/m^3/d. However the VLR amounted to only 1-3 kg COD/m^3/d (with 13 kg of COD-solids/m^3 reactor and a corresponding SLR of 0.1-0.3 kg COD/ kg solids-COD/d) as no more wastewater was available. The installation was running very stable; the buffer could maintain the COD load variations such that VFA concentrations in the AFR did not exceed 300 mg/l. The sludge production amounted to 2-5 % of the converted COD. The sludge residence time (SRT) was 60 days (at a hydraulic residence time (HRT) of 7-8 days). The results of the 500-m^3 prototype of reactor correspond well with the results of the previous pilot study.

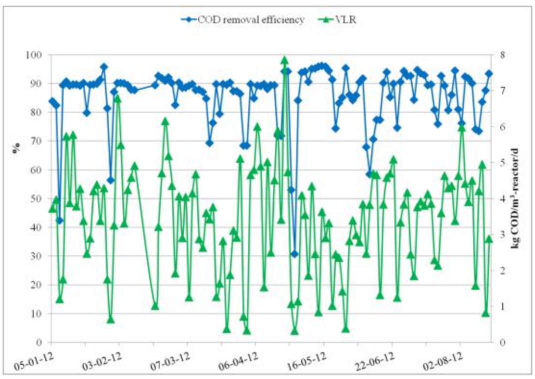

Figure 4: Results of COD removal efficiency and VLR at the ice cream factory.

Results of COD removal at Ben&Jerry's

On average 90 % of the COD (influent COD of 20 g/l on average) is removed and the biogas production corresponds well with the COD converted (0.6 m^3/kg COD-removed). The daily variations in the COD load (deriving from production sewer water (CIP) and waste ice cream) are high; the variation of fats in the influent appeared to be too high. At the moment the plant is fed with a more stable load which is easy to manage as the influent COD load consists for 50 % of waste ice cream which is very concentrated and therefore easy to buffer.

Fat/oil removal

At ITC a few weeks after inoculation (March 2010) fats were removed over 99 %. The concentrations of extractable hydrolysed and non-hydrolysed fats in the effluent were less than 40 mg/l (figure 3b). Flocks were formed which could be well retained by means of flotation. The variation in types and concentrations of fats and oil in the influent did not seem to disturb the system. Analyses showed that fat could make up to 35 % of the COD of the flocks; higher percentages were avoided by buffering of fats in the influent. Only high concentrations of fat-COD in the sludge (> 50 % of the total COD) could disturb the system: the VFA in the reactor increased and fat accumulated. Similar results were described in literature for LCFA (Long Chain Fatty Acids)-fed digesters (Kuang et al., 2002). However the inhibition was reversible, this was also found in another study (Pereira et al., 2005). The separation of the skimmed fats and oil in the small buffer tank prevented high ratios of fat-COD over total COD and allowed controlled dosing of fats and oily compounds. No fat layers were formed in the reactor: the mixing with biogas risers appeared to be very effective. It was observed that the presence of fat had a positive influence on the compactness of the flock. In literature the syntrophic populations that are needed for good LCFA conversion were described in which acetogens, acetoclastic and hydrotrophic methanogens play an important role (Sousa et al., 2010). A compact biomass structure is needed for this purpose. Furthermore it is described that adsorbed LCFA or fat might facilitate the transport of the poor water-soluble hydrogen (Alves, 2009). In that case the compact flocks with adsorbed fatty compounds could be the optimum biomass structure to perform the conversions. The flock structure might facilitate the hydrolysing processes that precede the β-oxidation and methanogenesis as well. From the results of both plants it can be concluded that the fats and oil present in the food wastewater were effectively converted. The mixing and flotation of the flocculent biomass with biogas seems to be very successful in attaining high conversion rates of fats and oil.

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