Intermittent Operation of UASB Reactors as a Strategy to Enhance Anaerobic Degradation of Dairy Wastewaters

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Abstract: - This investigation is related to the optimization of the anaerobic degradation of dairy wastewater by means of intermittent operation of UASB reactors. The intermittent operation consists of a series of sequential feed and feedless periods. The results show that with the intermittent operation the same COD removals are attained as with continuous operation; furthermore the introduction of a feedless period has benefits in terms of methanization of the removed substrates pointing to a more complete biological degradation of the organic matter. The performance and stability of intermittent UASB reactors is enhanced by effluent recirculation during the feedless period. Finally it is shown that the intermittent operation causes a change in microbial biomass towards a higher capacity for the degradation of complex substrates.

Keywords: Anaerobic, adaptation, optimization, UASB, intermittent, dairy wastewater

1 Introduction

When used for the treatment of complex wastewater containing significant amounts of fat (e.g. slaughterhouse, dairy) the continuous operation of Upflow Anaerobic Sludge Blanket (UASB) reactors has proved to cause problems of scum and sludge layer on top of the reactors with subsequent biomass washout [1-3]. Also the high COD accumulation in the sludge bed has been reported as leading to unstable performance of the reactors on the long run. Recent research done on anaerobic degradation of complex fat containing wastewater showed that the initial removal mechanism is mainly adsorption [4,1,5]. The adsorption of organic matter by anaerobic sludge occurs very rapidly in the sludge bed but is not followed by an immediate biological degradation of the adsorbed organic matter since the kinetics of biological degradation is much slower than the adsorption phenomena [6]. As a consequence heavy accumulation of organic matter in continuous treatment systems has been observed both at lab-scale and full-scale UASB reactors treating complex fat containing substrates. According to Jeganathan et al. [7] the factor that most influences high rate reactor performance is the FOG (fats, oils and greases) accumulation rather than the FOG concentration in the reactor feed. The substrate that poses more problems in the anaerobic degradation of dairy wastewater is the fatty matter and the long chain fatty acids resulting from milk fat hydrolysis, especially oleic acid [2]. In an investigation on slaughterhouse wastewater treatment in UASB reactors Sayed [8], suggested that the most adequate form of treating complex fat containing wastewater would be the use of flocculent sludge and intermittent feeding. This operating mode was recommended also by Lettinga and Hulshoff Pol [9], for complex wastewater, namely dairy wastewater. The intermittent operation consists of an interruption of the reactor feeding during a certain amount of time (feedless or stabilization period) allowing a more complete biological degradation of the substrates accumulated in the sludge bed during the feed period. Some works have been done on intermittent UASB reactors as an alternative path to improve the performance of
anaerobic systems applied to complex fat containing wastewater [10 - 13].

2 Problem Formulation

To date no results are found in literature concerning a systematic comparison of the performance of intermittent vs. continuous UASB reactors used for dairy effluents when operated at comparable loads and inoculated with the same initial sludge. On the other hand, no data exists on eventual microbial changes underlying the good performance of intermittent UASB systems reported in literature. The aim of this work was to compare continuous vs. intermittent UASB reactors used for the treatment of dairy effluents, both in terms of reactor performance and in terms of biomass modification caused by intermittent operation. The operating performance was accessed in terms of methanization of the removed COD since this is a parameter with significant influence on long term operation. The modifications in anaerobic bacterial populations caused by the introduction of a feedless or stabilization period on the operation of UASB reactors were investigated by determining the ectoenzymatic activity with a model substrate.

2.1 Materials and Methods

Three UASB reactors made of Perspex were used with a height of 86.4 cm and a working volume of 6 litres. The temperature was kept at (35±1)°C by means of water jackets. Biogas production was monitored with wet gas meters (Schlumberger). The reactors were inoculated with flocculent sludge from a medium load industrial anaerobic reactor. The inoculation sludge had a specific methanogenic activity (SMA) of 6.9 ml CH₄/g VSS/d measured with sodium acetate at (35±1)°C. The reactors were operated for 8 months. The intermittent UASB reactors (A and B) were operated with a feed period of 48 hours with a hydraulic retention time (HRT) of 12 hours followed by 48 hours without feed for sludge stabilization. The continuous UASB reactor (C) was operated with a 12 hours HRT. The operating conditions resulted from previous optimization studies [12]. The three UASB reactors were operated with a global load of 14 g COD/L/day; during the feed periods the load of for the intermittent reactors was 28 g COD/L/day. All reactors received equal amounts of feed COD in each 96 hours period. The feed for the reactors was prepared daily diluting semi-skimmed milk, nutrients and alkalinity with tap water. All analytic determinations in this work were made according to Standard Methods [14]. The methane content in the biogas was analyzed in a Shimadzu GC-9A equipped with a Supelco Molecular Sieve 5Å column and a TCD (T = 100°C) the injection temperature was 45°C and Helium was used as a carrier gas (P = 4.4 kg/cm²).

Ectoenzymatic activity in Ringer-diluted water samples and in sediment suspensions was determined fluorimetrically (Jasco FP-777 Fluorometer) as the maximum hydrolysis rate (Hm) of model substrate for lipase (4-methylumbelliferyl-oleate), according to Hoppe [15]. Analysis were made triplicate and incubations were conducted for 2-7 hours at 20ºC. The model substrate was obtained from Sigma-Aldrich.

3 Problem Solution

Figure 1 presents the profiles for soluble COD (CODs) and volatile suspended solids for two cycles of intermittent operation (reactors A and B). It can be seen that the CODs and VSS in the effluent rise during the first day of feeding and decrease in the second day. The CODs by the end of the feed period reaches the low values it presented for the beginning of the same period whilst the VSS remained slightly higher. Although the intermittent operation forces the reactor to a series of start-ups which are always sensible phases of reactor operation it can be said that for this load (14 g COD/L/d) this operation mode does not pose significant stress upon the reactors. Intermittent UASB reactor A had some operation problems due to power failure and heating equipment. These problems were clearly reflected upon the CODs in the effluent from this reactor.
As a strategy to improve the performance of reactor A from day 152 onwards effluent recirculation was implemented during the feedless period. The effluent recirculation flow during this period was twice the fresh feed flow used in the feeding period. The effect of effluent recirculation is clearly noticeable in the behavior of the reactor both in terms of total COD (CODt) and soluble COD (CODs) concentration of the effluent and in terms of reactor stability (Figures 3 and 4 and Table 1). The data on Figures 3 and 4 also confirm the stable behavior of the intermittent operation that was mentioned above.

Table 1 – Average values for the operation of intermittent (A, B) and continuous (C) reactors

<table>
<thead>
<tr>
<th>Reactor</th>
<th>SST (mg/L)</th>
<th>SSV (mg/L)</th>
<th>CODs (mg/L)</th>
<th>CODt (mg/L)</th>
<th>% COD removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>886</td>
<td>731</td>
<td>541</td>
<td>953</td>
<td>96</td>
</tr>
<tr>
<td>A2</td>
<td>529</td>
<td>448</td>
<td>323</td>
<td>847</td>
<td>98</td>
</tr>
<tr>
<td>B</td>
<td>582</td>
<td>502</td>
<td>318</td>
<td>492</td>
<td>493</td>
</tr>
<tr>
<td>C</td>
<td>407</td>
<td>314</td>
<td>101</td>
<td>901</td>
<td>98</td>
</tr>
</tbody>
</table>

A1 = Reactor A without recirculation
A2 = Reactor A with recirculation
% COD removal: 
=100×(CODtFeed – CODsEffluent)/CODtFeed

The COD concentration in the effluent from the intermittent reactors is always higher than for the
continuous reactor. That is because the feed concentration for the intermittent operation is twice as high as for the continuous operation. Other operating parameters, like pH and VFA were also similar for both reactors (respectively 7.6 and 100-150 mg AcH/L) the VFA being slightly higher for the intermittent reactors with occasional peaks (up to 500 mg AcH/L). The methane productions for the reactors B (intermittent) and C (continuous) are depicted in Figure 5. The average methane production for the intermittent reactor was about 16% higher than for the continuous reactor. The average percentage of methanization of the removed COD attained with the intermittent reactor was 88% as compared to 68% with the continuous reactor.

![Figure 5 – Methane productions for the intermittent and the continuous operation](image)

This higher methanization percentage points to a more complete biological degradation of the organic matter and suggests a better adaptation of the biomass in the intermittent reactor for the degradation of the complex substrate. The COD balances are depicted in Figure 6 for one intermittent cycle for reactor B and the same operation period for reactor C.

![Figure 6 – Methanization of the removed COD in continuous and intermittent operation (days 153-157)](image)

For this intermittent cycle the methanization reached around 90% whilst for the continuous operation it only reached 69%. The percentage of methanization of the removed COD that is accomplished during the feedless period of intermittent operation is around 11% of the total methanization obtained in the total cycle (feed period + feedless period). So the increase in the methanization reached by means of the intermittent operation is not entirely due to the surplus of methane produced during the feedless period. There is a large effect also in the methanization capacity of the sludge during the feed period. Some recent works have demonstrated that the biomass present in the sludge and the biomass present in the supernatant have some different characteristics [16]. For this reason the tests for ectoenzymatic activity were performed with sludge samples and also with supernatant samples from the continuous and the intermittent reactors. The results (Table 2) clearly show that the microbial population developed in the intermittent reactor has a higher capacity to degrade the complex substrate present in the dairy wastewater (oleate). This difference in the degrading capacity for oleate is evident both in the sludge samples and in the supernatant samples.
Table 2 – Ectoenzymatic activity of biomass with model substrate

<table>
<thead>
<tr>
<th></th>
<th>C (continuous)</th>
<th>B (intermittent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge (μmol C/gsw)</td>
<td>82</td>
<td>132.6</td>
</tr>
<tr>
<td>Supernatant (μmol C/L)</td>
<td>116.2</td>
<td>167.8</td>
</tr>
</tbody>
</table>

4 Conclusion
For the same applied loads the intermittent operation of UASB reactors treating milk wastewater allows COD removal efficiencies as high as the continuous operation (around 98%). The intermittent operation results in higher methane productions than the continuous operation, which suggests a more complete biological degradation of the removed organic matter in the intermittent reactor as compared to the continuous reactor. On the other hand, the intermittent operation also causes changes in the biomass in order to enhance its capacity to degrade the complex substrates present in the dairy wastewater. This means that the intermittent operation is a valid form of improving the biomass adaptation towards the degradation of complex substrates present in the dairy wastewater. The effluent recirculation during the feddless periods of intermittent operation resulted in improved reactor performance and stability. The results obtained in this work point to the intermittent operation of anaerobic reactors as a valid strategy to improve the degradation of complex fat containing wastewater.

References:
