Continuous anaerobic acidification of municipal wastewater using secondary sludge as seed

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Abstract

Fermentation of wastewater is a process by which facultative bacteria hydrolyze the organic contaminants and transform them in volatile fatty acids (VFA). In a continuous reactor without recycling of microorganisms the only source of facultative bacteria is the wastewater and its concentration is relatively low. In this research it was considered that the concentration of facultative bacteria could be increased with the addition of low amounts of secondary sludge. The experimental procedure was made in a 450-liter pilot reactor. Secondary sludge from a full-scale activated sludge facility was used as seed with different concentrations. The main conclusions of the study show that the suspended solids from primary and secondary sludge were hydrolyzed, independently from their origin. Effluent TSS and VSS were consistently lower than influent ones. The removal rates of TSS and VSS are for both 32%. Dissolved COD removal was 21% and total COD removal 28%. The loss of combined TSS and COD can only be explained through the formation and stripping of CO₂. The formation of the different VFA did not follow a pattern. Only the concentration of acetic acid changed significantly with HRT and influent TSS. The concentration of propionic, butyric, and isobutyric acids remained relatively unchanged under different operational conditions. Only a small fraction of the organisms contained in the secondary sludge take active part in the biochemical hydrolysis reactions.

Keywords: Fermentation, anaerobic process, wastewater, hydrolysis, acidification

INTRODUCTION

The anaerobic fermentation of wastewater is well known as a first biochemical step in anaerobic digestion. The separation of the acidification phase (preacidification) from methanogenesis is a normal practice for a better performance of UASB reactors (Kaijun et al., 1997; Alexiou et al., 1994; Fox and Pohland1994). Some researchers refer to the preacidification step as a “selector” to allow phosphate accumulation and to reduce the risk of bulking sludge in activated sludge systems (Randall,1994). Danesh and Oleskiewicz (1996) observed that activated sludge systems used for biological nutrient removal improve when fed with wastewater rich in volatile fatty acids (VFA). These small molecules are readily biodegradable under aerobic conditions and can be fed to any biological wastewater treatment system, reducing the reaction times (von Münch, 1997; González-Martínez et al, 1987; González-Martínez and Norouzian 1984).

The main objective of this research was to analyze the performance of a completely mixed continuous anaerobic reactor when fed with municipal wastewater and, as seed, with secondary sludge from a full-scale activated sludge system.
METHOD

A continuous, completely mixed pilot reactor with 450-liter net volume was built and fed with municipal wastewater (figure 1). One ¼ HP-pump was used as influent pump and another one to provide mixing. Peristaltic pumps were used for sampling, to provide a molasses solution and to adjust the influent SST concentration. Fresh secondary sludge from the return sludge of an activated sludge system was pumped to adjust the desired SST at the influent. To increase the influent COD in the influent with constant 400 mg/l, a peristaltic pump fed continuously a molasses solution.

Considering the normal variations of the wastewater the influent COD was kept between 500 and 700 mg/l. The flow of all three feed pumps could be varied to adjust to the experimental conditions. The variables of the experimentation were the hydraulic retention time (HRT) and the secondary sludge concentration (TSSs) in the influent. Temperature and pH were not controlled. The secondary sludge solids were adjusted between 0 and 80 % of the influent TSS and the HRT was adjusted between 2.0 and 7.0 hours. Due to the normal variations of the wastewater, deviations of the preliminary set values were expected.

RESULTS

Suspended solids characteristics. Figure 2 indicates that the VSS in the influent solids represents 78% of the TSS and, for the effluent solids, this same ratio decreases slightly to 75%. During the fermentation processes only a small amount (3 %) of the VSS is reduced as an effect of the hydrolysis. No significant differences between TSS and VSS in the influent and effluent solids were observed. On the other hand, figure 3 shows a consistent decrease of the TSS during the biochemical transformations.

Comparing the influent TSS of the seed (secondary sludge) and the combined influent TSS (primary plus secondary sludge) with the effluent TSS, the effluent TSS is 32% under the influent values and 37% under the seed values. This means that 32 % of the TSS is hydrolyzed to soluble substances during the process, independently of the experimental conditions. The differences between the seed and combined TSS are not significant. Primary and secondary solids are affected similarly during the fermentation processes.
In figure 3, the average distance between seed and combined TSS represents an average value of 65 mg/l of primary solids in the raw wastewater before the addition of the seed and the molasses.

**COD removal.** Dissolved COD removal represent 21 % of the total influent COD (figure 4). Independently of the influent TSS and HRT variations, the removal had a correlation value of 0.90. Total COD removal shows an average value of 28 %, noting that the values are scattered but homogeneously under the influent COD values.

In order to analyze the results, including the combined influence of TSS and HRT, the solids or sludge load concept was used:

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\text{Solids load} = \frac{\text{TSS}}{\text{HRT}} \text{ (mgTSS/l·h)}
\]

The sludge load did not affect significantly the COD removal (figure 5). It was expected that, with increasing sludge load, the COD removal would increase for a constant influent COD. This was not the observed case. With increasing sludge load the reaction time for hydrolysis and VFA production decreases, but not the amount of substrate transformed. Not an identifiable pattern between sludge load and COD removal could be observed.

Considering homogeneous biochemical reactions, the effluent VFA concentration should be proportional to the influent substrate concentration, HRT and TSS present in the reactor. In figure 6 it can be observed that the VFA produced did not follow the expected behavior.

The effluent dissolved and total COD follow a definite pattern (figure 4) but the VFA did not present a definite relationship with the seed (solids) load (figure 6). A possible explanation is that the secondary sludge used as seed did not have homogeneous contents of living facultative bacteria.
over the weeks of the experimental runs. From this last figure it is clear that the VFA production cannot be related to the presence of secondary sludge in the influent.

**Volatile fatty acids.** The measured VFA indicate the presence of acetic, propionic, butyric, and isobutyric acids. In only one of the 28 experimental runs valeric acid was detected. Figure 6 shows the influence of the solids load on the VFA concentration and figure 7 the VFA production rate. In general, the VFA concentrations and the VFA production rate do not show any pattern related to the different operational conditions of the 28 runs. In figure 6, at lower loads, the distribution appears more scattered than at higher loads. Both combined and secondary sludge types show no tendencies that allow a dependency conclusion. Figure 7 shows no dependency of the secondary sludge load on the VFA production rate.

Figure 8 indicates that the VFA production rate decreases with increasing secondary solids concentration. No matter the results appear scattered a pattern can be identified: the concentration of secondary solids reduce the VFA production rate indicating the importance of the primary sludge activity or the inhibiting characteristics of secondary sludge.

Over the pH range from 5.3 to 6.6, the pH value did not seem to influence the VFA production in a predictable manner.

The distribution of the different acids shows no tendencies as function of HRT and solids load (figure 9). The highest concentrations were those for acetic, then propionic, butyric and isobutyric acids. According to theoretical considerations, the higher the HRT (lower solids load), the lower the acetic concentration and higher the concentration of acids with larger molecular weights.

![Figure 6. VFA as function of the (seed) solids load.](image6)

![Figure 7. VFA production rate and solids load.](image7)

![Figure 8. VFA production rate and seed solids.](image8)
In this case, the concentrations of all VFA species do not change with increasing solids load (or decreasing HRT). Acetic acid was detected with concentrations between 50 and 130 mg/l; propionic acid presented concentrations between 30 and 90 mg/l; butyric and isobutyric acids showed the lowest concentrations under 50 mg/l.

When comparing the VFA in the effluent with the influent TSS, a similar image than that of figure 9 is obtained. Theoretically, increasing the influent TSS should produce an increasing transformation of COD and TSS into VFA when active microorganisms increase their number and the overall transformation rates. These were not the observed results.

![Figure 9. VFA species according to the solids load.](image)

A different VFA distribution should be observed with increasing solids load. Figures 6 to 9 shows that the total VFA production follows not a definite pattern, leading to unexpected conclusions. A possible explanation for these inconsistencies is that the amounts of living facultative bacteria in the raw wastewater and the secondary sludge used as seed were not consistent over the weeks necessary to perform the experimental work. It is also possible that the determination of TSS and VSS did not provide a good analysis tool knowing that they do not distinguish the amount of living organisms in the TSS.

**CONCLUSIONS**

1. Suspended solids from primary and secondary sludge were hydrolyzed, independently from their origin. Effluent TSS and VSS were consistently lower than the influent ones.
2. The fermentation processes did not significantly affect the VSS/TSS ratio. The removal rates of both TSS and VSS combined primary and secondary sludge were 32%.
3. Dissolved and total COD removal was 21 and 28 %, respectively. The loss of TSS and COD can only be explained through the formation and stripping of CO₂.
4. The formation of the different VFA did not follow a pattern when related to the operational conditions of the system. Acetic acid showed the highest concentrations followed by propionic, butyric, and isobutyric acids. Valeric acid was detected only in one of the 28 runs.
5. The VFA production rate decreases with increasing secondary sludge concentration.
6. The quality of the secondary sludge did not allow a good analysis of the acidification processes under the selected conditions.

**REFERENCES**


