TWO-STAGE SYSTEM OF ANAEROBIC DIGESTER

LILIANA TOPLICEANU
MIHAELA MOISA

University of Bacau
"Al Piru" School

Abstract: The present paper continues a study about the types of anaerobic digesters for solid wastes compared on technical and biological performance and reliability. The two-stage systems are the most complex, and most expensive of all systems Their greatest advantage lies in the buffering of the organic loading rate taking place in the first stage, allowing a more constant feeding rate of methanogenic second stage. Theses aspects are presented and discussed in the next files.

Keywords: dry systems, wet systems, organic waste, biomethanization.

1. INTRODUCTION

The anaerobic digesters for solid wastes are classified in one-stage, two-stage, and batch systems. The two-stage systems are the most complex, and most expensive of all systems Their greatest advantage lies in the buffering of the organic loading rate taking place in the first stage, allowing a more constant feeding rate of methanogenic second stage. This is a substantial advantage in the case of substrates whose degradation is limited by the methanogenesis rather than by the hydrilysis, e.g. cellulose-poor kitchen wstes. These wastes, being very rapidly acidified, tend to inhibit the methanogenesis in one-stage reactors when the feedstock is not adequately mixed, buffered and dosed. The special type of two-stage system, with biomass accumulation devices in the second stage, displays a larger resistance toward toxicants and inhibiting substances such as armonia.

So, the justification of two- and multi-stage systems is that the overall conversion process of organic fraction of municipal solid waste (OFMSW) to biogas is mediated by a sequence of biochemical reactions which do not necessarily share the same optimal environmental conditions. Optimizing these reactions separately in different stages or reactors may lead to a larger overall reaction rate and biogas yield [1]. Typically, two stages are used where the first one harbors the liquefaction-acidification reactions, with a rate limited by the hydrolysis of cellulose, and the second one harbors the acetogenesis and methanogenesis, with a rate limited by the slow microbial growth rate [2]. With these two steps occurring in distinct reactors, it becomes possible to increase the rate of methanogenesis by designing the second reactor with a biomass retention scheme or other means. In parallel, it is possible to increase the rate of hydrolysis in the first stage by using microaerophilic conditions [3]. The application of these principles has led to a great variety of two-stage designs.

2. THE IMPORTANCE OF TWO-STAGE SYSTEM

The main advantage of two-stage systems is a greater biological reliability for wastes which cause unstable performance in one-stage systems (Table 1). Biological reliability is achieved by adequate buffering and mixing of incoming wastes, by precisely-controlled feeding rate and, if possible, by resorting to co-digestion with other types of wastes. Industrial applications have up to now displayed little acceptance for two-stage systems as these represent only ca. 10 % of the current treatment capacity.

A distinction is made in this paper between two-stage systems with and without a biomass retention scheme in the second stage. The reason for using this criterion is that the retention of biomass within a reactor is an important variable in determining the biological stability of the digester. Unstable performance can be caused either by fluctuations of organic loading rate, due to wastes heterogeneity or discontinuous feeding, or by wastes excessively charged with inhibiting substances such as nitrogen. All types of two-stage systems, regardless of whether biomass is accumulated or not, provides some protection against the fluctuations of organic rate.

Table 1. Advantages and disadvantages of two-stage systems

Criteria	**Advantages**	**Disadvantages**
- Technical:	- Design flexibility	- Complex
- Biological	- More reliable for cellulose-poor kitchen waste - Only reliable design (with biomass retention) for C/N < 20	- Smaller biogas yield (when solids not methanogenized)
-Economical & Environ methanogemental	- Less heavy metal in compost- (when solids not methanogenized)	- Larger investment

3. TWO-STAGE SYSTEM WITHOUT BIOMASS RETENTION

3.1. Technical evaluation

The simplest designs of two-stage systems, used primarily in laboratory investigations, are two complete mix reactors in series [3]. The technical features of each reactor are comparable to those presented in a precedent paper for the one-stage wet system. The wastes are shredded and diluted with process water to ca. 10 % total solids content – TS, before entering the first digester.

Another possible design is the combination in series of two plug-flow reactors, either in the “wet-wet” or “dry-dry” mode. The source-sorted biowaste, finely chopped and diluted to 12 % TS, rises upward through a series of perforated plates placed within the reactors (Figure 1). Uniform upward movement is imparted by pulsating pumps which also ensure localized short term mixing via time-controlled impulses creating rapid rising of the liquid column. The impulses also push the biogas through the plate apertures. This design, applied under wet thermophilic conditions, is able to ensure, without any internal moving parts, adequate mixing and a plug flow mode which guarantees complete hygienization since short-circuiting is avoided. Additionally this design is not conducive to the formation of the thick floating scum layer commonly plaguing wet reactors.

In the BRV process, the source-separated biowastes, adjusted to 34 % TS, pass through an aerobic upstream stage where organics are partially hydrolyzed and ca. 2 % lost through respiration. The reason for conducting the hydrolysis stage under microaerophilic conditions is that the loss of COD (chemical oxygen demand) due to respiration is more than compensated by a higher extent of liquefaction, which, proceeds faster than under anaerobic conditions. After a two-day retention time, the pre-digested wastes are pumped through methanogenic reactors in a horizontal plug flow mode. The digestion lasts 25 days at 55 °C and 22 % TS.

The primary advantages of this system are the use of dry conditions which reduces the size of the digesters and the use of piston flow which affords complete hygienization without a pasteurization step. The horizontal flow requires however the use of floor scrapers to eliminate the heavy material from the reactor and mixing equipment inside the reactor to prevent the formation of a crust layer.

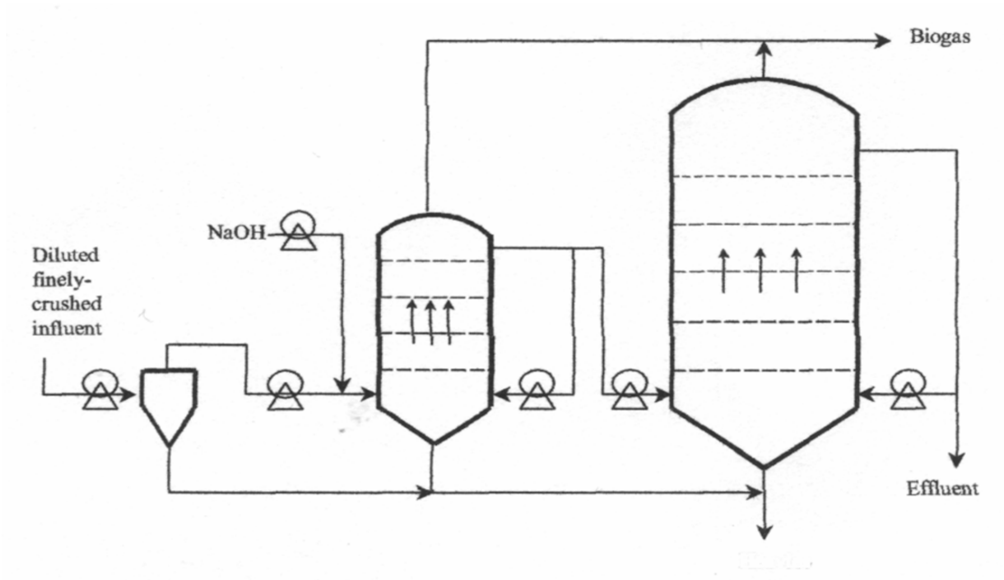

Figure 1. The two-stage system applicable to source-sorted biowastes,

3.2. Biological performance

The main advantage of the two-stage system is the greater biological stability it affords for very rapidly degradable wastes like fruits and vegetables [4]. The reason commonly invoked is that the slower metabolism of methanogens relative to acidogens would lead to inhibiting accumulation of acids. Theoretically, this reasoning seems illogical as it would suffice to adjust the organic loading rate (OLR) of a one-stage system to the rate which can be handled by the methanogens to avoid any risk of acid accumulation. The OLR chosen in this manner for a one-stage system would not be inferior to that of a two-stage system.

In the practice the greater reliability of two-stage systems has indeed at times been observed, at least in discontinuously-fed laboratory set-ups. For example, we compared the performances of the one- and two-stage systems, using pilot complete mix reactors fed with very rapidly hydrolyzable biowastes from fruit and vegetable markets. While the one-stage system failed at 3.3 kg VS (volatile solids content)/m^3.d, the performance of the two-stage plant remained stable at an overall system OLR of 7 kg VS/m^3.d. This departure from theoretical predictions can be explained by the fact that actually applied OLR vary a great deal with time and space due to the heterogeneity of wastes and due to the discontinuous working of the feeding pump. In cases where special care is taken to mix the feed thoroughly and dose it at constant OLR, one-stage wet systems are as reliable and performing as two-stage systems even for highly degradable agro-industrial wastes, provided these have a C/N above 20.

The short-lived fluctuations of the actually applied OLR may lead to short-lived overloading in the one-stage system. In a two-stage system, however, these OLR fluctuations are somewhat buffered by the first stage, so that the OLR applied to the second stage is more uniform in time and space. In fact, this buffering of OLR in the first stage is somewhat similar to the effect of the plug flow pattern often used in the one-stage dry systems because a plug flow with external mixing leaves large zones in the digester unexposed to transient high concentrations of inhibitors. Highly biodegradable kitchen wastes can indeed be digested in single-stage reactors provided these are thoroughly mixed before feeding and provided feeding occurs continuously, or at least five days per week as in the one-stage dry Dranco plant. This plant, which treats kitchen wastes, achieves a mean OLR of 5.0 kg VS/m^3.d with 80 % VS destruction.

The second type of inhibition, resulting from unbalanced average composition of feed rather than from transient shock load, is, as deleterious to two-stage systems as it is to one-stage systems, except in cases where two-stage systems are equipped with a biomass retention scheme in the second stage, e.g. via attached growth on a fixed bed. In terms of biogas yields and maximum sustainable -OLR_{max}, little difference can be noted between one- and two-stage systems, at least for these two-stage systems without biomass retention.

4. TWO-STAGE SYSTEM WITH BIOMASS RETENTION SCHEME

4.1. Technical evaluation

In order to increase rates and resistance to shock loads or inhibiting substances, it is desirable to achieve high cell densities of the slowly-growing methanogenic consortium in the second stage. There are two basic ways to achieve this.

The first method to increase the concentration of methanogens in the second stage is to uncouple the hydraulic and solids retention time, thereby raising the solid content in the methanogenic reactor. These accumulated solids represent active biomass only in the case of wastes leaving no more than 5-15 % of their original solid content as residual suspended solids inside the reactor. This design will therefore be effective only for highly hydrolyzable kitchen or market wastes [5]. One way to uncouple the solid and hydraulic retention times is to use a contact reactor with internal clarifier. Another way is to filter the effluent of the second stage on a membrane and return the concentrate in the reactor in order to retain the bacteria [6]. Plugging of the microfiltration membranes can be avoided using a high cross-flow velocity achieved via reinjection of biogas. Excessive biomass was purged in a separate outlet line.

Another method to increase the concentration of slowly-growing methanogens in the second stage is to design the latter with support material allowing attached growth, high cell densities and long sludge age. The prerequisite of this design avenue is that the feed to the attached growth reactor be very little charged with suspended particles, which means that the suspended solids remaining after the hydrolysis (first) stage should be removed. Two industrial processes, the BTA and Biopercolat designs, are based on these principles.

In the BTA wet-wet process, illustrated in Fig. 2, the 10 % TS pulp exiting the pasteurization step is dewatered and the liquor directly sent to the methanogenic reactor [7]. The solid cake is resuspended in process water and hydrolyzed in a complete mix reactor under mesophilic conditions. The pH within the hydrolysis reactor is maintained in the range 6-7 by recirculation process water from the methanogenic reactor.

The output stream of the hydrolysis reactor is once more dewatered and the liquor fed to the methanogenic reactor. The latter, receiving only liquid effluents, is designed as a fixed film loop reactor in order to increase biomass concentration and age. From a technical point of view, this design shares the same limitations as the one-stage wet system, i.e. short-circuiting, foaming, sinking of heavies, fouling of the impeller blades with plastic foils, obstruction of pipes with long objects such as sticks, and loss of 10-30 % of the incoming VS caused by the removal of the rake fraction in the hydropulper. The major drawback of the wet-wet system remains however its technical complexity as four reactors are necessary to achieve what other systems achieve in a single reactor.

The Biopercolat follows the same principles as the BTA process, with the difference that the first stage is carried out under dry and microaerophilic conditions and is continuously percolated with process water to accelerate the liquefaction reaction [7]. The flush water, containing up to 100 g COD/I, is fed to an anaerobic plug-flow filter filled with a support material. The separate optimization of the first stage, via aeration, and of the second stage, via biofilm growth, allows the system to run at the exceedingly low overall retention time of 7 days.

The Biopercolat system is quite innovative from a technical point of view. In order to prevent the channeling and clogging typically occurring in dry percolated systems, percolation occurs in large slowly-rotating sieve drums with 1 mm mesh openings. In the methanogenic filter, a pulsating motion is imparted to the horizontal plug flow in order to prevent plugging of the support material, improve mass transfer of substrates to biofilm, and improve degasification.

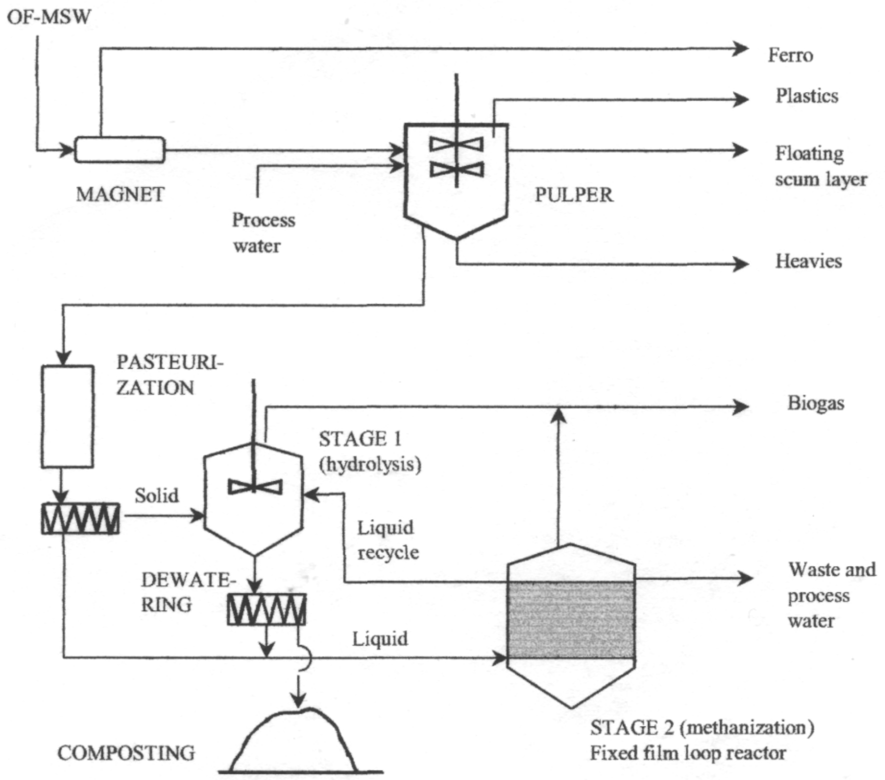

Figure 2. Two-stage wet-wet design with a biomass retention scheme in the second stage (BTA process).

3.2. Biological performance

As a consequence of the higher biomass concentration in two-stage designs with attached growth, greater resistance toward inhibiting chemicals is achieved. We compared one- and two-stage wet pilot plants for the treatment of highly biodegradable agro-industrial wastes. While the one-stage system failed at OLR of 4 kg VS/m^3.d for those wastes which yielded ca. 5 g NH4$^+$/1 due to ammonium inhibition, the same wastes could be processed in the two-stage system at OLR of 8 kg VS/tn^3.d without impairment of methanogenesis. The stability of the methanogenesis at such elevated ammonium concentration was attributed to the higher bacterial concentration and age which could be obtained in the contact reactor with internal clarifier used in the second stage.

Another consequence of two-stage systems with biomass retention is the possibility of applying higher OLR in the methanogenic reactor, with values up to 10 and 15 kg VS/m .d reported for the BTA and Biopercolat processes, respectively. These relatively high rates were however only achieved at the cost of 20-30 % lower biogas yields, due to the fact that the coarse solid particles remaining after the short hydrolysis stage, which still contain residual biodegradable polymers, are not fed to the methanogenic digester.

Two-stage systems may start playing a more and more important role, especially if treatment of industrial wastes is to be combined with that of biowaste and hygienization may require a separate treatment step at higher temperatures. Batch systems also still need to make a breakthrough, but chances are that hygienization as well as safety requirements will make these systems more difficult to introduce.

4. CONCLUSIONS

It must be recognized that anaerobic digestion of solid wastes still has to compete vigorously with aerobic composting. This is in part related to the fact that composting is a long-established technology which generally requires less initial investment. However, current energy prices and targeted reduction of fossil fuel combustion in the coming decades will draw increasingly more attention towards anaerobic digestion. Indeed, the amount of gas potentially recovered from the solid wastes is substantial at the level of a country. In the framework of the Kyoto agreements, many countries in Europe have agreed to stimulate the production of methane from wastes, e.g. by subsidizing the electricity from biogas by as much as 0.1 euro/kW.h. The latter certainly will be a major support for anaerobic digestion of complex wastes.

The European Union has set the goal to increase the fraction of electricity produced with renewable resources to 12.5 % in 2010. Electricity generated from municipal solid waste by means of anaerobic digestion can make a significant contribution towards this goal.

REFERENCES

[1] Angelidaki, I. *Anaerobic thermophilic process : the effect of lipids and ammonia*. Ph.D. thesis, (1992) Dept of Biotechnology, Technical Univ. of Denmark, Lyngby, DK
[2] Ghosh, S., Henry, M.P., Sajjad, A., Mensinger, M.C. and Arora, J.L. *Pilot-cale gasification of MSW by high-rate and two-phase anaerobic digestion*. In Int.Symp. Anaerobic Dig. Solid Waste, held in Barcelona, June 15-17, 1999.
[3] Capela, I. F., Azeiteiro, C. et al, *Effects on pre-treatment (composting) on the anaerobic digestion of primary sludges from a bleached kraft pulp mill.* In II Int. Symp. Anaerobic Dig. Solid Waste, held in Barcelona, June 15-17, 1999, vol. 1, pp. 113-120.
[4] Garcia, J.L. and Schalk, P. *Biopercolat-procedure*. In Int. Symp. Anaerobic Dig. Solid Waste, Barcelona, June 15-17, 1999, vol. 2, pp. 298-301.
[5] Laclos, H., Desbois, S. and Saint-Joly, C. *Anaerobic digestion of municipal solid organic waste,* In Proc. 8th Int. Conf. on Anaerobic Dig., May 25-29, 1997, vol. 2, pp. 232-238, Technical Univ. of Denmark, Lyngby, DK.
[6] Pavan, P., Battistoni, P., Mata-Alvarez, J. Performance of thermophilic semi-dry nerobic digestion process changing the feed biodegradability. In II Int. Symp. Anaerobic Dig. Solid Waste, held in Barcelona, June 15-17, 1999, vol. 1, pp. 57-64.
[7] Madokoro et al., 1999
[8] Kubler, H. and Wild, M. *The BTA-process high rate biomethanisation of biogenous solid wastes.* In Proc. Int. Symp. on Anaerobic Digestion of Solid Waste, Venice, 14-17 April, 1992