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# Critical Technology Factors of Biogas Plants Using Mixed Materials

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**Abstract:** Biogas production is a well spread, up-to-date technology to utilise biomass in Europe. The applied technologies are based on mesophile, or thermophile methods, and the mixture of them. The applicable, effective energy production for biomass always depends on the input materials and the essential preparation of them, the "recipe", and technological parameters that must be strictly controlled during the process. Based on the operation of an existing Hungarian biogas plant our article deals with these critical points of the biogas production technology.

**Key words:** biogas, sewage sludge, fermentation, foam formation

## 1. Background

Biogas plants use a wide variety of primer materials such as whole corn silage, root crops, seed crops residues etc. that make the operation of the biogas plant more stabile as their structure is mainly constant in time. A biogas plant is quite similar to a ruminant animal. For example in the feeding of cows the so called TMR (Total Mixed Ratio) system is used, that means the same composition of the feeds are used during the whole season. The stomach flora adapt to the feed and able to transform rapidly the desired quantity.

The biogas plant we studied within the frame of our research project applies different kind of input materials as a mixture. The mixing ratio also differs from the usual. In agricultural circumstances biomass is used as primer and waste from animal husbandry as sounder material is used for biogas production. When the composition of the materials is almost constant, and the material supply is continuous the operation of the biogas plant is acceptable.

The other kind of technology is based on fermentation of sewage sludge from waste water plants. The constitution of the input material is also constant, but max 10% deviation can be accepted.

In the examined technology the ratio of the sewage sludge is 55-60% (respect to the dry matter). The sewage sludge as an input material comes from 8-10 settlements and the consignments differ very much from each other. 10% of the total amount of input materials is waste from food industry.

Having an up-to-date computer based control system, the electric power production of the biogas plant is approximately 2.0 MW (see Fig. 1).

Mixture and the chopping of the input materials (cow manure, corn silage) take place in the SZK, from where will be filled to the F1 or F2 digesters. First mixing of the liquid manure, sewage sludge and other liquid materials happens in the heated pre-storage bunker (ET). According to the EEC hygiene regulation, pasteurising for min. 1 hour (hereby for 4 hours) at a temperature of 70°C is prescribed. Pasteurising process of the following materials take place in HT:

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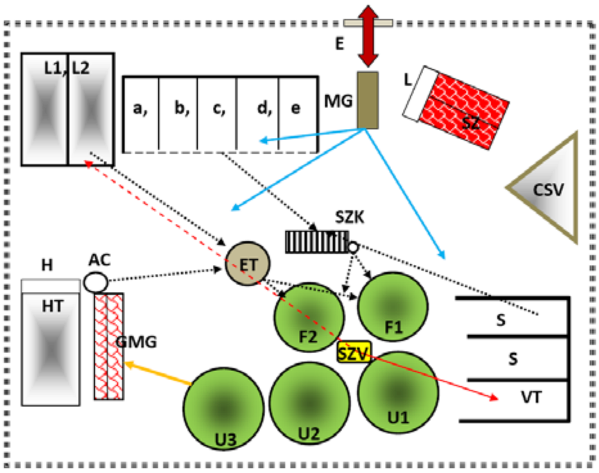


E = Main entrance, L = Logistics station, SZ = Social facility, MG = Weighing of the input material, CSV = rainwater tank, a, b, c, d, e = Temporary storage, S = Silage storage, VT = Separated storage of end product, L1, L2 = End storage of the liquid material (lagoons), ET = Pre-storage and mixer for liquids SZK = mixing, and chopping of solids H = Hygienisation, HT = Storage, GMG = Gas motors, F1, F2 = Digester, U1, U2, U3 = Second digester, SZV = Pump station and separation, AC = disinfectant (autoclave)

**Fig. 1 Scheme of the biogas plant.**

- food waste
- fat
- cooked oil
- fat coming from grease traps

One of the most important criterium in the profit oriented biogas plants for the stable electric and heat energy production is the continuous biogas supply for the gasmotors. Such companies have an obligation of pre-anouncing the production of the electric power for the next 24 hours. In the case of any deviation sanction occour (more than 20% deviation causes 15-18% price reduction).

The biggest technological problem in the investigated biogas plant is the foaming of the digesters. One of the targets of our research work is to discover of the possible reasons of this undesirable phenomenon. Rich literature sources can be found for this kind of operational problem, but the practical experience for the solution is quite limited.

## 2. Sewage Sludge

The average ratio of the sewage sludge utilisation in the existing biogas plants is 10-15%. In our case the value of 40-50% is quite perspective for the agricultural soil resource management and the energy receiving aspect as well. According to the 50/2001 (IV. 3) regulation only well prepared sewage sludge can be utilised in the agricultural production. The sewage sludge utilisation is a subject to authorisation.

Nowadays 58-60% of the total amount is placed on agricultural lands, 20-22% is placed on landfills, 1-2% is incinerated, and the rest is utilised on an unknown way. According to the previous plans in 2015, 390.000 tonnes of sewage sludge will be utilised in the agriculture a year. Fermentation of the sewage sludge results energy saving, and the specific expenses of the sewage sludge cleaning process will also decrease. The fermented sewage sludge as the end product in the biogas plant can be placed without environmental problems. This could improve the quality of life, and the ecological condition of the environment.

## 3. Possible Reasons of the Foaming

According to the results of some research [1] foaming is a quite common technology problem. In 16 biogas plants investigated by them, the average duration of foaming was 1-21 days while 20-50% of the gas quantity was lost.

The main reasons for the foaming problem in the Lemwig biogas plant (Denmark) was the composition of the input material and the insufficient mixing as well.

According to their measurements the communities of bacteria don’t have effect on foaming, meaning the indifference of the filamentous bacteria to the foam formation in the co-substrate based reactor. At the same time they confirm that filamentous bacteria, especially Gordonia species and Microthrixparvicella facilitate foaming in sewage sludge fermentation technologies.

Their articles emphasize the organic overloading and subsequently the accumulation of acetic acid as the cause of foam formation in wastewater sludge digesters (corresponding to Boe at al.).

Moreno-Andrade et al. (2004) [2] performed a research with 10% starting value of sewage sludge that was increased continuously for 30 days. During the start up of the plant the sewage sludge was recirculated, and the pH value was set-up by lime.

According to McCarty the sewage sludge as a substrate contains all the necessary nutrients for the bacteria. 60-75% of the dry content of sewage sludge is organic material. In the mesophilic range 12-13 days are needed for the decomposition of the sewage sludge having 70% organic matter content. Under 50% of organic matter content the anaerobic decomposition is not economic.

Oláh et al. emphasize that direct charging of the organic matter into the reactor can cause the overload. In this case intensive foaming may occur within 30 minutes and the methane content of the biogas decrease as well.

The most important factors of foaming and solutions (based on literature):

- Composition of the organic matter should be constant, that helps to develop a well-balanced microbiological population (max. 4 kg/day/$m^3$ dry material).
- The best value of the C/N ratio is 15-30/1. When the level of nitrogen is low the carbon elaboration decreases, while too much nitrogen reduces the methane production.
- Methane-producing bacteria live best under neutral to slightly alkaline conditions. Under anaerobic conditions, the pH will normally take on a value of between 7 and 7.5 (less then 6.8 can be harmful). In the presence of fermentative anaerobic organisms the optimal pH value is 4.5-6.3.
- The optimal dry matter content is 6-15% in the case of mechanical mixing. Continuous mixing is needed in order to maintain process stability and improving the efficiency within the digester.
- Fluctuation of the temperature reduces the methane development.
- Optimal temperature of the mesophilic bacteria is 35-40°C.
- Dry matter content determines the load of the reactor. Quantity and the concentration together give the correct information.
- Volatile acids, the $HCO_3$ alkalinity and the ammonium concentration must be determined.
- Volatile acid concentration is less than 1000 mg acetic acid/l equivalent
- FOS/TAC value: 03-04 is good, but depends on the system. 0.2-0.3 is good in the second digester and the lagoon. When the value is less than 0.2 there is a lack of organic matter. Above 0.4 the organic matter content is too much.
- Air intake is needed for hydrogen sulphide oxidation (admissible content is 2-2.5% of the gas)

Applied materials for producing biogas in the investigated plant:

- corn silage
- cow manure
- liquid manure
- sewage sludge (from 12 waste water plants)
- food residues
- oil-, and fat sludge
- expired food ( cold cuts, ice cream, chips)

The most important factors affecting the anaerobe digestion:

- fresh inoculums
- constitution and concentration of the input material
- solids retention time, and the system load by the organic matter
- temperature, mixing and flowing compliance
- exclusion of toxic matter

In order to keep the desired efficiency, controlling some of the above mentioned factors (load, temperature, mixing) the operator is able to intervene, but changing the features of the substrate (chemical, microbiological constitution, toxic components) is complicated or sometimes impossible.

Discovering the real problem in the investigated plant, as a first step the constitution of the input material was examined with a special focus on energy and ash content. At the beginning of the research project we established a target: preparing recipients to create optimal inputs for the reactors.

Determining parameters are:

- C/N
- FOS/TAC
- pH

Components are introduced in Table 1. Components are signed $J_e$. The desired ratio can be reached by changing the ratio of the components considering the reactor dry matter (SZA) capacity, and the load (SZA/kg).

Calculation must be fulfilled for all the used input materials everytime, when feeding the reactor and always if any changes occour.

## 4. Features of Sewage Sludge

Results of energetic and chemical tests of 3-3 samples (chosen from all the 12 input materials coming from different waste water plants) can be studied on Figs. 2-7. Dry matter content of the samples differs very much, but the C content is almost the same.

**Table 1 Calculating table for the appropriate components ratio.**

| Matter/Feature | Dimension | A | | B | | C..etc.. | | Σinp. | ΣJe inp.. |
|---|---|---|---|---|---|---|---|---|---|
| | | kg | Je* | kg | Je* | kg | Je* | kg | Je (desired) |
| C/N | ratio | | | | | | | | 15-25 |
| SZA | (%) | | | | | | | | 8-12 |
| pH | | | | | | | | | 6.5-7.8 |
| TAC $CaCO_3$ | (mg/l) | | | | | | | | 13000 |
| FOS acetic acid equivalent | (mg/l) | | | | | | | | 3000 |
| FOS/TAC | ratio | | | | | | | | 2.1-3.0 |
| KOI | (mg/l) | | | | | | | | 3000 |
| $NH_3$-N | (mg/l) | | | | | | | | 1600 |
| Phosphate | (mg/l) | | | | | | | | 10.5-12 |

Calculating example:

Je = feature determination, e.g.: C/N

Materials weigh separately and sum total (kg)

$\Sigma kg_{inp.} = Akg+Bkg+Ckg+..= \Sigma kg$

Features separately and sum total (C/N)

$\Sigma Je_{inp} = (Akg*AJe+Bkg*BJe+Ckg*CJe…)/(Akg+Bkg+Ckg+..) = \Sigma Je$ (sum C/N)

Significant difference can be found in the pH value and the C/N ratio of the samples. It is a big problem and intervention needed to make a better balance.

During the fermentation process C and the dry matter content decreases in the reactors. Compensation of the difference in the C/N ratio was carried out by manure and corn silage dosage. Because of the F2 digester operated using more sewage sludge, the dry matter content and the C/N ratio was disadvantageous, and the foaming was more intensive there (see Fig. 4).

Features of the other input materials were also tested. Significant difference was detected in the dry matter content, but they have more advantageous C/N ratio than the sewage sludge (see Fig. 5).

Feeding of the reactors can be realised from different sources, as the pre-storage bunker (ET), chopper (SZK) and the autoclave (AC) (see Fig. 1). All the reactors can

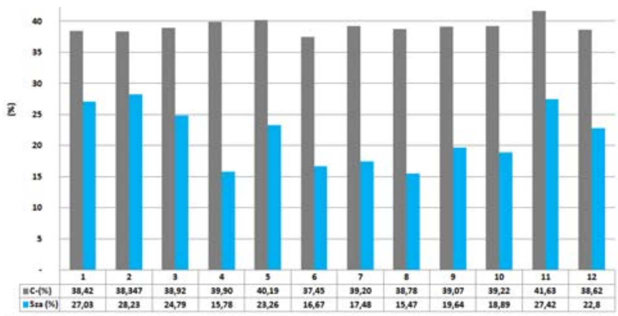


**Fig. 2 Dry matter content of the samples.**

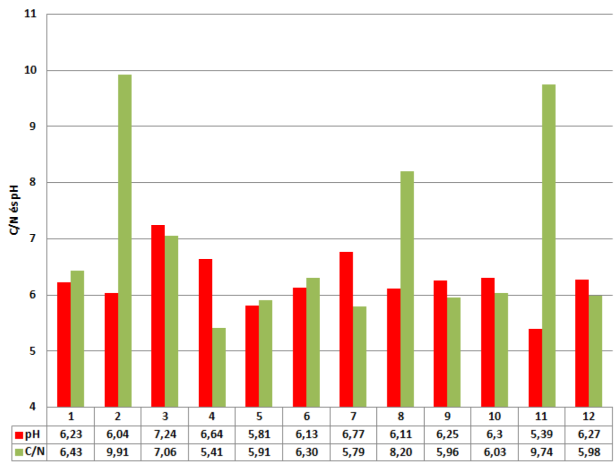


**Fig. 3 pH value and C/N ratio (average).**

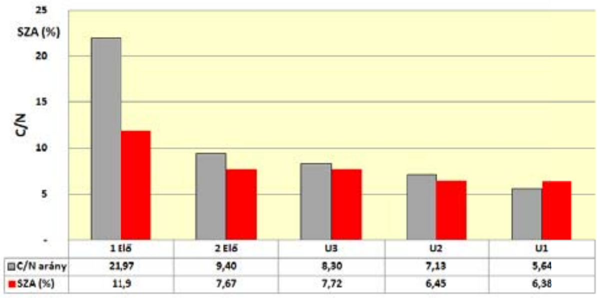


**Fig. 4 Changing the C/N ratio and the dry matter content in the reactors.**

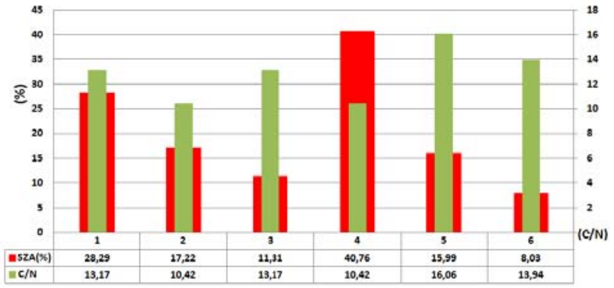


**Fig. 5 Features of the other materials.**
1) food residues, 2) liquid manure, 3) oil-, and fat sludge, 4) manure, 5) expired food ( cold cuts, ice cream, chips) 6) cooked oil.

be supplied by the central pump from all the mentioned sources. This can be important in the case of foaming.

## 5. Utilisation of the End Product

With the help of the pump the substrate can flow from the second digesters to the separator, from where the liquid phase flows to the lagoon, and the solid phase goes to the concrete bunkers (VT).

Some quantity of the solid residues — as have a high energy content — can be re-used in the fermentor in order to increase the C content. The dry end product can be used as nutrient on the fields or can be composted. Also some quantity of the liquid from the lagoon can be used to help for pre-mixing (in order to control the dry content).

According to the current regulations the liquid end product (digestate) must be handled as liquid manure and may be spread out to the fields only one time a year. It must be ploughed into the soil. Problems of this procedure are:

- plants are not able to utilise the so much quantity
- sometimes nutrients are not available when plants need

The high moisture content is an advantage of spreading the liquid end product, and it can help amlot in dought. Other economical advantages can also be mentioned as digestate may substitute fertilisers, can be used well on sand soil (0.5-0.7 GWh/year electric capacity ensure digestate for 1.0-1.2 ha ploughland).

## 6. Effect of the Sewage Sludge and the Sand Content of the Manure

Sewage sludge and manure contain significant quantity of sand (quartz sand). As the particles are abrasive very much, the sand content is disadvantageous for the technical equipments (mainly for the chopper, and mixers). Sand stays at the bottom of the lagoon. This must be considered when using the digestate as diluent. Only precipitated digestate can be used for dilution!

The intensive abrasion makes serious problem in the chopper operation (Fig. 6). Hammers wore rapidly, that cause inappropriate chopping. Fibrous material reduces the mixing efficiency that courses less gas production.

Strengthen of the edges (e.g., welding using hard metal) is suggested to avoid the intensive abrasion of the hammers.

## 7. Effect of the Mixers

The digesters (F1, F2) have three same sized moveable mixers, and a bigger fix mixer. The second digesters (U1, U2, U3) have three, same sized moveable mixers. The vertical position of the smaller mixers can be changed, and they can be turned with 60 degrees from left to right.


**Fig. 6 Abrasion of the hammers: A-original hammer, B-one month operated hammer, C-two months operated hammer.**

Mixers play an important role in homogenisation. Optimal streamline inside the reactors supports the adequate heat exchange for the heating pipeline that is needed for ensuring the homogeny reactor temperature. According to our monitoring the mixing process is inappropriate. Finding the optimal adjustment of the mixers modelling and simulation of the mixing process was performed. 135 variations were analysed. In a next article, we report on the modelling of mixing.

## 8. Results

During the 5 months research project our effort oriented to find the optimal feeding of the reactors. Ad hoc breakdowns of the system and sometimes stoppages of the needed input material supply resulted unwanted delays (see Fig. 7).

Application of the simulation resulted moderated foaming, and the number of the malfunctions of the system reduced. The specific gas production, relative to the input material increased (see Table 2). During three months the electric capacity value grown from 61.2 % to 68.7%.

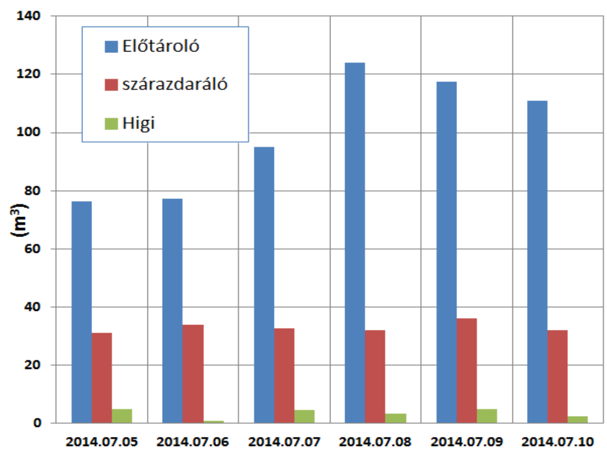


**Fig. 7 Fed materials (blue-pre-storage, brown-solid chopper, green-autoclave).**

**Table 2 Electric power capacity of the system.**

| Rated capacity MWh/month | Effective capacity (MWh/month) | Calculated cap. from inputs** (MWh/month) | Calculated cap. from inputs * MWh/month) |
|---|---|---|---|
| 1480.56 | 592.2 | 1017.6 | 916.2 |
| 100% | 40.0% | 68.7% | 61.2% |

This proves our targets and the benefits of the research work, that would be sensible to continue in order to optimise the applied technology.

## 9. Summary

This article dealt with an operational segment of a biogas plant. As far as we can prognosticate biogas plants will be wide spread in the near future in Hungary as the concept is supported by the Government. Furthermore the concept of settling biogas plants near by wastewater treatment plants is supported by the European Union. Biogas plant can be established in the area of a wastewater treatment plant, but the idea of serving a biogas plant by at least 2-3 sewage treatment plants seems to be more effective and economic. Usually the most important problems derive from the great variety of the input materials and the very much difference in content of them. Foaming is maybe the most serious malfunction. Operation without any troublesome can be observed mainly where recipes are used in the technology based on laboratory tests, focusing all the critical parameters and features of the input materials. If feeding is consistent, then the specific gas production ($m^3$ gas/kg input material) increases. In Hungary the annual sewage production is 500.000 t, and only 20% is utilised for biogas production. A significant amount is sent to landfills, although the anaerobic digestion is the best solution considering the ecological and economical aspect. The end-products of the biogas plants are energy (electric and heat as well) and good quality manure that can be used well in the plant production technologies.

## References

[1] P. G. Kougias, K. Boe, S. O. Thong, L. A. Kristensen and I. Angelidaki, Anaerobic digestion foaming in full-scale biogas plants: A survey on causes and solutions ISWA, 2014.

[2] I. Moreno-Andrade and G. Buitron, Influence of the origin of the inoculum on the anaerobic biodegradability test, *Water Sci. and Technol.* 49 (1) (2004).