

Conducting a Transient-State Anaerobic Digestion Process at Start-up Phase of a Biogas Plant

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Abstract

In a biological start-up phase, caused by the opening of digesters for technical revisions, the biological process collapsed. The digesters from an on-farm biogas plant were incorrectly fed during the start-up phase with high-organic contents feedstock, including high carbohydrate substrate (silage, milled cereals). As a result of this type of operation, the values of the essential parameters that indicating the equilibrium state of the microbiological and biochemical process have deteriorated. Samples were taken and analyzed in the laboratory. During a two-months period of monitoring and conducting the anaerobic digestion process, a steady state of the biotechnological was reached. Subsequently, mixture recipe for feeding the digesters after reaching the neutral pH and the maximum FOS/TAC value of 0.4, have been established according to the materials available on the farm. Cow manure will constitute the main substrate with important microorganic input, this organic material being available in large quantities in biogas operator's own farm. Maize silage is available as the main substrate with high energy input. To increase economics of the process, it is recommended to feed the digester with residual raw materials, available in the area of the biogas plant operator.

Keywords: anaerobic digestion, biogas plant, start-up, transient-state process

1. Introduction

Against the backdrop of the continuing climb in global energy prices, energy recovery from organic residues and waste streams is becoming an ever more attractive proposition. Alongside the generation of storable renewable energy, the distributed production of biogas can help not only to develop rural regions, but also to strengthen agro-food industry. Thanks to the positive statutory framework for renewable energy and environment protection of European Union (EU Green Deal, Fit for 55 package, REPowerEU [1,2,3]), the production and utilization of biogas needs to rapidly expand in next years. Unlike western European countries, such as Germany for

example, where around 9500 biogas plants are operated, the Romanian biogas sector (11 biogas plants in operation in the entire country in 2022) needs a sustained growth to reach a similar size, considering the potential of Romania and particularly west region [4,5,6] to deliver necessary feedstock to produce biogas/biomethane.

In this research, our team collaborated with a biogas plant operating in a cattle farm in Timis county to restart an anaerobic digestion process in a biogas plant where the biologic process was stopped after the digesters were opened and the contents from digesters were discarded in order to replace defective parts.

2. Materials and methods

Start-up processes differ from normal operation in that the system has not yet reached the steady state. The processes taking place are subject to constant changes to the process parameters. In

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order to be able to run the process safely at full load in this state, a greater measuring density is required than in normal operation because the process is unstable and is liable to collapse much more quickly. After a faulty feeding of the digester by biogas operator, the anaerobic digestion process collapsed and biogas production has stopped. Here, our team intervened in directing the bioprocess in order to reach the steady state of the anaerobic digestion process and

continuous production of biogas. As a result of incorrect operation of the digester, the values of the essential parameters that indicate the equilibrium state of the microbiological and biochemical process have deteriorated (table 1). Samples were taken and analyzed in the laboratory. The values indicate that the anaerobic digestion process is in collapse, the fed material is not degraded, the microorganisms are not active.

Table 1. Values of main parameters in digester no. 1 (D1) at the beginning of the research

| | pH | DM | ODM | FOS/TAC | Semification of main operation parameters |
|-------------------------|---------|------|------|--------------|---|
| Values in Digester no.1 | 5.00 | 6.2 | 5.3 | 296 ! | FOS/TAC ≥ 0,6 – too much undigested organic mater, feeding must to stop! |
| Optimal values | 7.5-8.5 | 8-11 | 7-10 | 0.4-0.2 | Bioprocess is in steady state, continuously producing biogas |

(DM = dry mater; ODM = organic dry mater)

What is the FOS/TAC ratio? The Federal Agricultural Research Centre in Germany developed the FOS/TAC analysis from a titration test (Nordmann-Methode) in order to determine the quotient of the acid concentration and the buffer capacity in the fermentation substrate. **FOS** stands for *Flüchtige Organische Säuren*, i.e. volatile organic acids, and is measured in mg HAcq/l, while **TAC** stands for *Totales Anorganisches Carbonat*, i.e. total inorganic carbonate (alkaline buffer capacity), and is measured in mg CaCO₃/l [7]. The FOS/TAC ratio has long been recognised as a guide value for assessing fermentation processes. It enables process problems extending as far as the imminent inversion of the digester biology to be detected at an early stage, so that countermeasures can be initiated [8].

The biological process in the reactor **Digester No. 1 (D1)** is unbalanced. FOS/TAC is alarming, extremely high indicating high quantity of undigested raw material accumulating in D1. At this FOS/TAC the accumulation of volatile organic acids is evident, which lowers the pH and inhibits the methanogenesis process. A first measure to restore the balance of the biological process would be to feed the reactor with fresh cow manure. However, a high feed rate does not help to remedy this situation. According to previous experience [9], our team proposed to dramatically reduce the feeding rate of the reactors to let the microbes consume the excess organic acids built up from overfeeding. By feeding

starchy matter by the operator, the acidifying microorganisms rapidly consumed the polysaccharides and produced excess organic acids. The methanogenic microorganisms did not have time to consume the acids, the pH decreased and methanogenic bacteria are inhibited.

The recommendation made to the operator of the biogas plant is:

- Stopping feeding with energy-rich substrate, carbohydrates (silage, biomass, etc.).
- Evacuation of a considerable amount of fermentation medium from the digester;
- Addition of manure available in the area (ideally cattle manure);
- After bringing the suspension to the working level in the digester, inoculum from a biogas station operated in the correct operating parameters to be added (biogas plant in Arad is the closest);
- The digester to be left without stirring for 2 days, after which the intermittent stirring begins: in the first 5 days, once a day for homogenization, after which stirring to be made according to the technology supplier's recommendation;
- Substrate feeding starts when pH reaches neutral value.
- Before the first feed, a samples are harvested from the digester for FOS/TAC and pH analysis;
- The feeding will be made according to a graph similar to the example in figure 1.

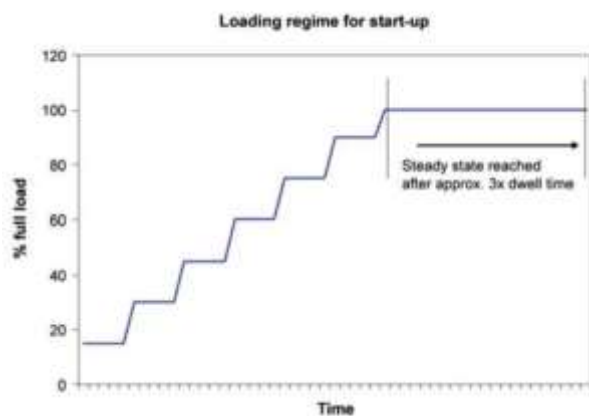


Figure 1. Loading regime for start-up the anaerobic digestion process

3. Results and discussion

Restoring the microbiology balance of the reactors

After emptying a significant amount of the fermentation medium from D1 and adding pig manure, beef manure and digestate from another biogas plant, the pH increased from 5 to 5.35. The

FOS/TAC value remained extremely high (reaching value 4) during the first two weeks (until August 1, 2022). After the addition of 10 tons of calcium carbonate in two stages in the first week of August, after another two weeks, in which the feeding of the reactor was stopped, the FOS/TAC value dropped to 2.5, and the pH reached the threshold value of 7 (at the middle of August, pH reached 7.28). At the same date, the level of digesting material in reactor D2 reached the working level. The next day, the engine of the cogeneration unit has started since the methane content in biogas reached 50%.

Manure feeding did not decrease the FOS/TAC value to values below 1, ideally to 0.2 (the target value for a balanced process). After laboratory analyses, it was established that manure add considerable amount of organic acids that inhibit methanogenic microorganisms.

In the first week of September, the reactor started to be gradually fed with high content carbon substrate (high C/N ratio) at their availability (e.g. corn silage).

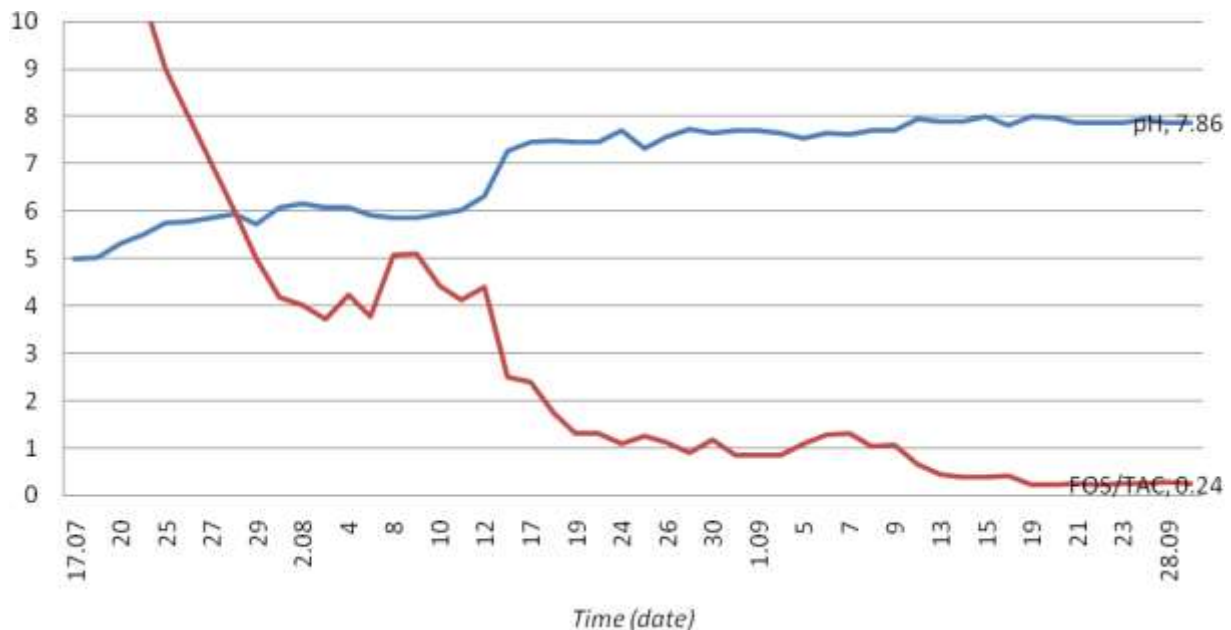


Figure 2. Evolution of pH and FOS/TAC parameters in start-up period of the anaerobic digestion

The raw material available on the farm that satisfies the carbon requirement of the reactor is corn silage. In the next three weeks (until the end of September), corn silage was fed progressively, from 6, to 8, to 10, to 15 tons / day. The feeding regime maintained the bioprocess parameters

within the optimal limits for the operation of the process, and at the end of the september, the *steady state proces* was reached considering the followings (see figure 2):

- FOS/TAC value stabilized under 0.3;
- pH stabilized at values over 7.6;

➤ 50% production efficiency of the cogeneration unit was reached (cogeneration unit was able to be operated without stopping at the power of 500kW with the gas produced in the digesters D1 and D2). During a two-months period of monitoring and conducting the anaerobic digestion process, a *steady state* of the biotechnological process was reached. Subsequently, mixture recipe for feeding the digesters after reaching the neutral pH and the

maximum FOS/TAC value of 0.4, have been established according to the materials available on the farm. Cow manure will constitute the main substrate with important microorganic input, this organic material being available in large quantities in biogas operator's own farm. Maize silage is available as the main substrate with high energy input.

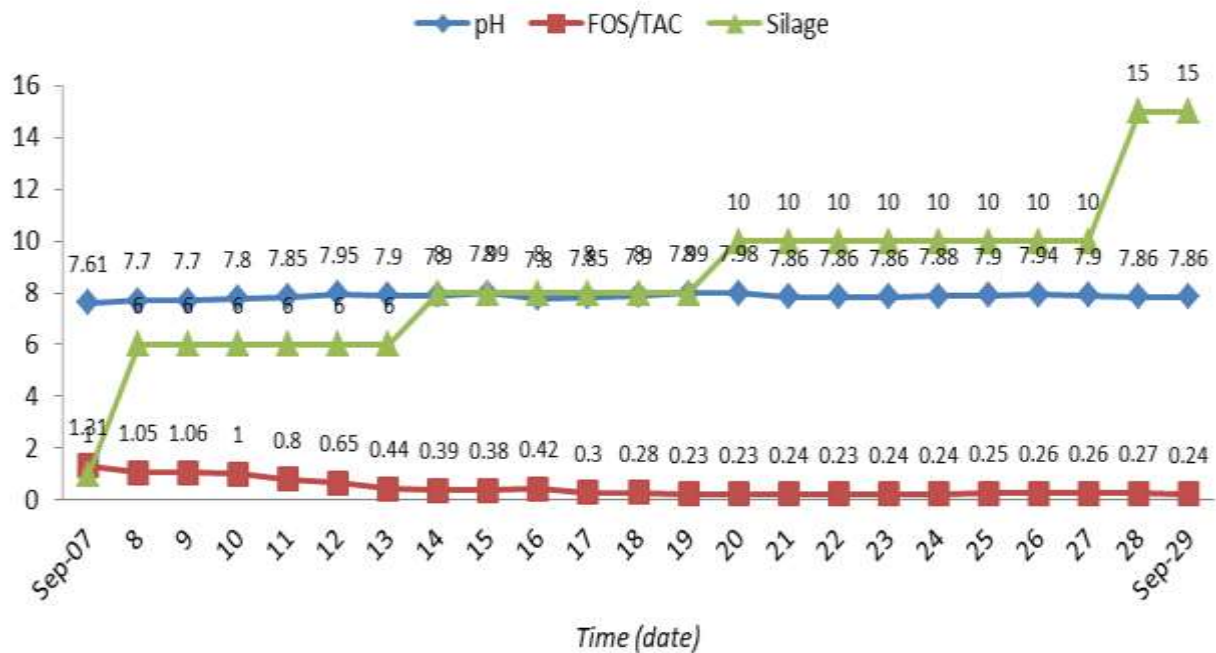


Figure 3. Evolution of pH and FOS/TAC parameters in start-up period in condition of increase feeding of carbon-reach substrate (corn silage)

In the next month (October 2022), the feeding rate of the biogas plant increased to 124 m³ of cow manure and 25 tones / day of corn silage and the production efficiency of the cogeneration unit reached 72% (the power of 720kW from the total installed power of 1 MW of the cogeneration unit).

Ideally, 100% production efficiency is targeted (the power of 1 MW of the cogeneration unit). To increase economics of the process, it is recommended to feed the digester with residual raw materials, available at zero costs in the area of the biogas plant operator.

4. Conclusions

The transient-state of the biotechnologic process from the biogas plant incorrectly operated during

the start-up phase by feeding high-organic contents feedstock, have been improved and directed to the equilibrium state of the microbiological and biochemical process. During the two-months period of monitoring and conducting the anaerobic digestion process, the steady state of the biotechnological was reached. Mixture recipe for feeding the digesters after reaching the neutral pH and the maximum FOS/TAC value of 0.4, have been established according to the materials available on the farm. Cow manure will constitute the main substrate with important microorganic input, this organic material being available in large quantities in biogas operator's own farm. Maize silage is available as substrate with high energy input and will constitute the main energy feedstock to produce biogas and green energy.

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