



Biogas Plants

Subjects: Environmental Sciences

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Definition

The biogas production technology has improved over the last years for the aim of reducing the costs of the process, increasing the biogas yields, and minimizing the greenhouse gas emissions. To obtain a stable and efficient biogas production, there are several design considerations and operational parameters to be taken into account. Besides, adapting the process to unanticipated conditions can be achieved by adequate monitoring of various operational parameters. This paper reviews the research that has been conducted over the last years. This review paper summarizes the developments in biogas design and operation, while highlighting the main factors that affect the efficiency of the anaerobic digestion process. The study's outcomes revealed that the optimum operational values of the main parameters may vary from one biogas plant to another. Additionally, the negative conditions that should be avoided while operating a biogas plant were identified.

1. Introduction

To meet the increased demand for energy needs and to reduce greenhouse gas emissions, the capacity of worldwide installed renewable energy systems has been doubled over the last decade ^{[1][2][3][4][5]}. This also applies to biogas as a source of renewable energy, where the number of biogas plants installed in Europe has been increased from 6227 in 2009 to reach 18,202 by the end of 2018 ^[6]. The total produced electricity from biogas reached 88 TWh in 2017, 40% of which was generated in Germany ^[4]. Hence, Germany is a leading country in this field^[6]. Biogas can be utilized—after treatment—in numerous applications, like electricity and heat generation, connection to the natural gas grid, or as biofuel in vehicles ^[7].

Anaerobic digestion is a biological process, in which the microorganisms degrade the complex organic matter to simpler components under anaerobic conditions to produce biogas and fertilizer ^{[6][8]}. This process has many environmental benefits, such as green energy production, organic waste treatment, environmental protection, and greenhouse gas emissions reduction ^{[2][9][10][11][12][13]}. The biodegradation of the complex organic matter undergoes four main steps. Namely, hydrolysis, acidogenesis, acetogenesis, and methanogenesis ^[3].

Biogas consists mainly of CH₄ and CO₂—the share of CH₄ is determined by the type of the feedstock fed into the biogas plant ^[2]. The different operational conditions also have significant effects on the biogas production potentials. In order to obtain the optimum biogas production with the lowest costs, the biogas plant design has to be optimized as per the needs and potentials. The design criteria of biogas plants (explained in the following section) should be considered for their construction ^[3]. Additionally, several parameters have to be controlled to prevent problems causing inhibition in biogas plants (Figure 1). Temperature, pH value, retention time, and organic loading rate have a direct effect on the microbial activity. Moreover, the physical features of the feedstock can vary, and it may contain toxic substances which can influence the microbial activities ^{[4][14]}.

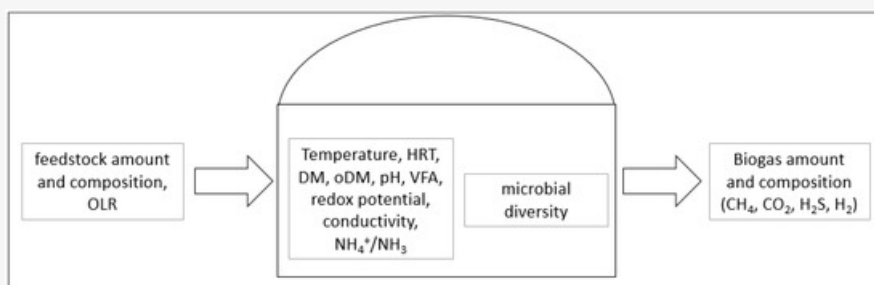


Figure 1. Operational parameters of the biogas plant. Adapted from Theurel and coauthors^[9]. OLR: Organic Loading Rate, HRT: Hydraulic Retention Time, DM: Dry Matter, oDM: organic Dry Matter, VFA (Volatile Fatty Acids).

2. Monitoring of the Operational Conditions in Biogas Plants

As mentioned before, the anaerobic digestion process includes four stages that come in sequence, where different kinds of microorganisms take part at each stage. In order to obtain a stable and efficient process, process monitoring is necessary [4][15][16]. Monitoring enables early detection of problems and disturbances and indicates the required adjustments to the operational parameters (to be within acceptable ranges).

In general, monitoring parameters of the biogas plants can be classified under three categories: parameters characterizing the process (feedstock type and quantity, biogas production amount and its quality, reactor temperature, dry matter concentration, ammonia concentration, and pH), parameters supplying early detection of instability (VFA, alkalinity, hydrogen concentration, redox potential, and other complex monitoring parameters), and variable process parameters defined by plant operators (OLR and HRT) [15].

The monitoring of the biogas plant's operational parameters can be achieved by on-line, at-line, and off-line analyzers. There is an increased interest in the on-line monitoring applications, due to the fast and automated process control. There are several parameters that can be monitored at the biogas plant on a real-time basis. The frequently on-line-monitored parameters in biogas plants are summarized in [Table 1](#).

Table 1. Studies conducted on biogas plants' operational parameters and their monitoring methods.

Parameter	Measurement method	Reference
Cobalt concentration in the high presence of iron concentrations	Total reflection X-ray fluorescence spectroscopy	[17]
VOCs (volatile organic compounds) emitted from different units of food waste anaerobic digestion plant	Portable GC-MS (gas chromatography–mass spectroscopy)	[18]
CH ₄ emissions from pressure relief valves of an agricultural biogas plant	Flow velocity and temperature sensors	[19]
Ammonia in biogas	Impedance measurement of biogas condensate in the gas room above the digester	[20]
Dissolved active trace elements in biogas	Total reflection X-ray fluorescence spectroscopy in dried digester slurry	[17]
H ₂ S in biogas	Gas responsive nano-switch (copper oxide composite)	[21]

Microbial communities depend on the substrate combinations	Sequencing of the 16S rRNA, biodegradable feedstock samples from eight different biogas plants	[22]
Controlling gas pressure in the digester	Programmable logic controller (PCL)	[23]
Ammonia in biomethane	Luminescent ammonia sensor based on an imidazole-containing Ru(II) polypyridyl complex immobilized on silica microspheres	[24]
pH, temperature, oxidation-reduction potential (ORP)	via electrodes, on-line monitoring with PCL	[25]
CO ₂ , CH ₄ , H ₂ O	On-line monitoring with a Supercontinuum laser-based off-resonant broadband photoacoustic spectroscopy	[26]
Different volatile fatty acids	On-line monitoring with total-reflectance Fourier-transformed infrared spectroscopy (ATR-MIR-FTIR)	[2]

The currently available technologies do not enable the monitoring of all operational parameters of the biogas plant. Therefore, samples have to be collected from the biogas plant and analyzed in individual facilities (off-line monitoring) [27]. Off-line monitoring takes place in the laboratory, where samples should be taken for the defined test. Unlike the off-line monitoring, on-line monitoring can provide real-time data on the plant's operation without any time loss for sampling, transfer, and analysis. A study about the on-line monitoring system was done in 2013 in Germany, and it showed that the majority of the biogas plants are equipped with on-line systems to monitor the electricity generation. Additionally, on-line systems were used to determine produced heat, input solid feedstock, biogas temperature, parasitic electricity demand, biogas volume, biogas composition and input liquid feedstock [15].

To improve monitoring systems of the biogas reactors, near infrared spectroscopy (NIR) and mid-infrared spectroscopy (MIR) are seen as promising technologies [9]. In order to obtain operation flexibility at biogas plants (e.g., changing operational parameters and feedstock type and amount), improvements to the biogas plants' monitoring technologies and applications are necessary [2][9][28].

3. Conclusions

Anaerobic digestion is an established technology, used to treat a wide variety of organic wastes. It is one of several biological processes that deliver economic and environmental benefits (i.e., producing bioenergy and/or biochemical while treating the organic fraction of waste). The anaerobic digestion process is complex—it includes various physical and biochemical reactions. The stability of the anaerobic digestion process is affected by many factors (e.g., the conditions inside and surrounding the reactor, the reactor's design, the operational parameters, etc.). In order to maintain a stable, efficient, and sustainable biogas production, the operational parameters should be determined and controlled.

The aim of this paper was to review and evaluate recent studies in the field to determine the critical parameters and their

impacts on the anaerobic digestion process, and consequently, on the biogas production. This paper presented a summary to the design parameters of the biogas plant, the significant digestion environmental conditions in the reactor, and the available monitoring and controlling technologies of the anaerobic digestion process (Figure 2).

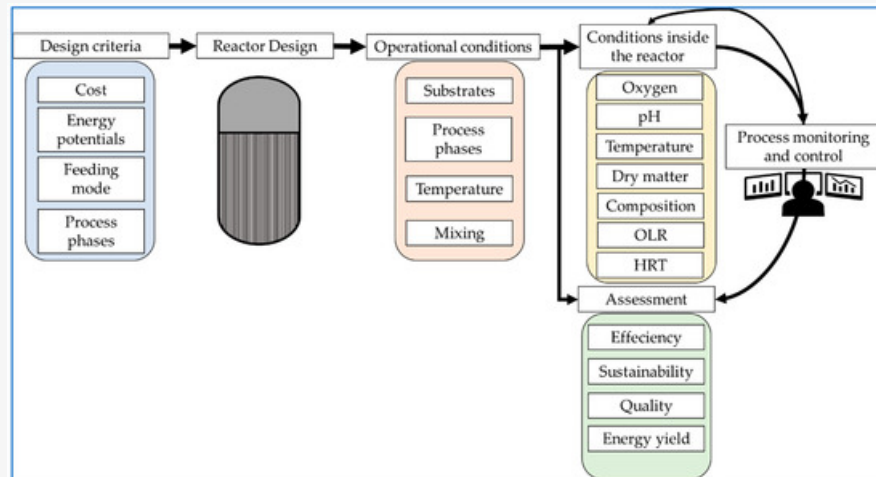


Figure 2. A summary of the paper's discussed aspect.

This review concludes that decisions regarding biogas plants' design, operation, and monitoring conditions depend on many factors (e.g., feedstock, temperature, pH, OLR, HRT, nutrients, inhibitors, biogas quality, etc.). However, the optimal range of the operational parameters varies from one biogas plant to another. Therefore, an inclusive monitoring system is required to enhance the performance of the anaerobic digestion process. Based on this review, it is recommended to improve and expand the available monitoring methods of the process in order to obtain an efficient, sustainable, and flexible operation of the biogas plants. To achieve that, further research needs to focus on the development of on-line, at-line, and off-line monitoring analyzers in the biogas plants.

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Keywords

biogas plants; anaerobic digestion; plant monitoring; bioenergy; process optimization

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