PARAMETER INFLUENCE ON THE ANAEROBIC DIGESTION KINETICS

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Procesul de stabilizare anaerobă este format dintr-o serie de reacţii strâns legate, ce evoluează în timp şi spaţiu în etape secvenţiale sau în paralel. Procesele de conversie a materiei în timpul stabilizării anaerobe pot fi clasificate îndouă categorii importante: reacţii biochimice şi fizico-chimice. Procesul de fermentare este limitat de viteza de desfăşurare a reacţiilor, având ca principală cauză capacitatea redusă de reacţie în absenţa unui oxidant puternic. A fost elaborat un model Simulink ce ulterior a fost validat cu rezultate experimentale. S-a studiat evoluţia producţiei de biogaz la modificarea unui singur parametru al modelului.

The anaerobic digestion process comprises a series of interlinked reactions evolving spatially as well as temporally in sequential and parallel steps. The conversion processes in anaerobic digestion processes can be divided into biochemical and physico-chemical reactions. Anaerobic stabilization processes are faced with limitations with respect to the reaction's kinetics. Kinetic limitations are set by the inertness of certain compounds to react in the absence of a strong oxidant. A Simulink model was elaborated and validated. The biogas production evolution when modifying a single parameter was studied.

Keywords: Anaerobic digestion, reaction, wastewater, kinetics

1. Introduction

During the treatment processes, the solids are removed from wastewater. The sludge from wastewater treatment plants is derived from primary, secondary and/or tertiary treatment processes. Most often, the produced sludge has a small concentration and a high biodegradable load.

Primary sludge is produced following to primary treatment, usually being sedimentation. Sedimentation is the removal of suspended solids from liquids by gravitational settling. If the suspended solids sedimentation rates are too small,

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chemical treatments like coagulation and flocculation are used in order to provide effective clarification.

Secondary sludge is generated from the biological treatment stage; stage that usually has the purpose of decomposing the organic matter through biological methods. The most often used is the activated sludge process, where the wastewater is aerated in an aeration basin in which micro-organisms metabolize the suspended and soluble organic matter. At the end of the process, the treated water has to go through a clarifier in order to be separated from the activated sludge. A part of the sludge separated in this secondary clarifier returns to the biological stage. The rest of the sludge, not necessary for the optimum development of the biological processes is surplus activated sludge.

In the sludge treatment stage of the wastewater treatment plant, the primary and secondary sludge described above are usually mixed together generating a type of sludge referred to as mixed sludge. This sludge has to pass through additional treatments, in order to reduce its water content, stabilize its organic matter and reduce the generation of odors, reduce its pathogen germs load, reduce its volume and global mass. Several treatments can be applied to the sludge to achieve this [1].

Biological anaerobic wastewater treatment processes (anaerobic digestion) have been widely used in life process and have been confirmed as a promising method for solving some energy and ecological problems in agriculture and agro-industry.

One of the mentioned methods transforms the sludge in a way that it is considered as a new type of sludge usually referred to as “digested sludge”. This so-called digestion process is the one that represents the subject of this paper.

Anaerobic digestion is based on the biological conversion of degradable compounds of sludge, in the absence of oxygen, into methane and carbon dioxide. The process is used in wastewater treatment plants with the main purpose of destruction of organic substances and pathogen reduction.

The advantage of using anaerobic digestion as a stabilization method for sludge is production of biogas, biogas that can be used in cogeneration unit to obtain the thermal energy needed for the anaerobic digestion and a part of the electrical energy consumed in the wastewater treatment processes[2]. The only drawback is the hydrogen sulphide, a gas that in contact with oxygen develops sulphuric acid, a strong mineral acid, which can damage the engines.

Another strategy used in developed countries is to obtain products from wastewater treatment sludge that can be sold, for example recovering valuable components of sludge, such as metals and chemical compounds. There are drawbacks in each case of sludge utilization, most usually the cost of the additional processing of sludge, but due to the environmental legislation at this point, solutions must be found.

2. Anaerobic digestion processes

Anaerobic digestion is a multistep process taking place in a closed digester. Anaerobic digestion kinetics is influenced by many factors of which we mention: temperature – usually kept in mesophilic domain, mixing – in order to keep the solids in the digester form forming deposits in the bottom side and to realize a good homogenization of the tank's content, hydraulic retention time which is decisive in the percent of stabilized organic matter; solids concentration in the influent; inhibitors.

The sludge stabilization is the result of multiple group of microorganism's activity. The first group of microorganisms turns the macromolecular organic matter in more simple compounds, like sugars, long chain fatty acids and amino acids. The solubilised compounds are converted by acidogenesis to hydrogen and carbon dioxide. In the acidogenesis phase, long chain fatty acids and alchoools are turned into acetic acid and hydrogen. In the last stage of the anaerobic digestion methanogenic bacteria methane is produced from acetic acid, carbon dioxide and hydrogen.

The process efficiency can be influenced by the different kinetics of the different groups of bacteria involved. Hydrolysis develops slowly, depending on the particulate matter introduced in the anaerobic digester, thus slowing down the whole process kinetics. Acidogenesis kinetics on the other hand is one order of magnitude higher than methanogenesis, so any disturbance that changes the methanogenic bacteria activity may have a negative effect on the process efficiency.

3. Anaerobic digestion modelling and simulation

Numerical modeling is a tool that allows to investigate the static and dynamic behavior of a system without doing – or at least reducing – the number of practical experiments. An experimental approach would be very time-consuming if all varieties of combinations and mixtures, temperature and pressure in a complex chemical process are be investigated to identify the optimum combination [3].

The simple models predict biogas by solving empirical algebraic equations without considering the fundamental biochemical reactions involved in the processes. In addition, since the models are not general, they are only good for the conditions they were based on. The complex models, however, are general; they include biochemical reactions and contain more inputs. The inputs include: hydraulic retention time, initial volatile solids concentration, bacterial growth rate, digester volume, flow rate of the sludge, and biochemical reactions.

Some of the benefits expected by using a generalized model for anaerobic digestion are: increased model application for full-scale plant design, operation and optimization [4]; further development work on process optimization and control, aimed at direct implementation in full-scale plants.

The used model is based on a two stage scheme for anaerobic digestion, considering both acetogenic and methanogenic bacteria [5].

$$\begin{cases} \frac{dX_1}{dt} = (\mu_1 - D)x_1 \\ \frac{dS_1}{dt} = -k_1\mu_1 x_1 + k_1 S_{1in}^0 - DS_1 \\ \frac{dX_2}{dt} = (\mu_2 - D)x_2 \\ \frac{dS_2}{dt} = k_3\mu_1 x_1 - k_2\mu_2 x_2 + D_2 S_{2in}^0 - DS_2 \\ Q = k_4\mu_2 x_2 \end{cases} \quad (1)$$

Where X[g/l] represents the bacteria concentration, S[g/l] the related substrate concentration, μ [1/day] the specific growth rate. Q[l/day] is the biogas flow rate. The elements in the differential equations with indices "1" represent the acidogenic phase and the ones with "2" refer to the methanogenic phase; k_i (i=1...4) are yield coefficients. D [1/day] is the total dilution rate, D_1 [1/day] is the dilution rate for the inlet soluble organics and D_2 [1/day] is the dilution rate for the inlet acetate.

For the specific growth rates, Monod law was considered. The disadvantage of using Monod law is that it doesn't take into account any possible substrate inhibitory effects at high concentrations. The law expresses the dependence of μ on the substrate concentration, as follows.

$$\mu = \frac{\mu_{\max} S}{k_S + S} \quad (2)$$

where μ_{max} is the maximum growth rate and k_S is the saturation constant.

A Simulink model was developed (see Figure 1), the first set of simulated results was obtained using the following values and conditions: D_1=0.0375=constant, D_2=0.0125=constant, k_i (i=1...4)=6.7, 4.2, 5 and 4.35, S_{1in}^0=7.5, S_{2in}^0=50. For the maximum growth rates we considered 0.2 respectively 0.25 [4]. The results are shown in Fig. 2.

The simulation results were as the ones found in similar studies [4], therefore the Simulink model was considered to be a valid one. It’s obvious that for both substrate reactions the concentration decreases with time.

The next step was to determine the initial parameter variation influence on the biogas production. The first parameter that was modified was the initial substrate concentration, being increased ten times. The result was a increase of 60% in the biogas production, as can be seen in Fig. 3.

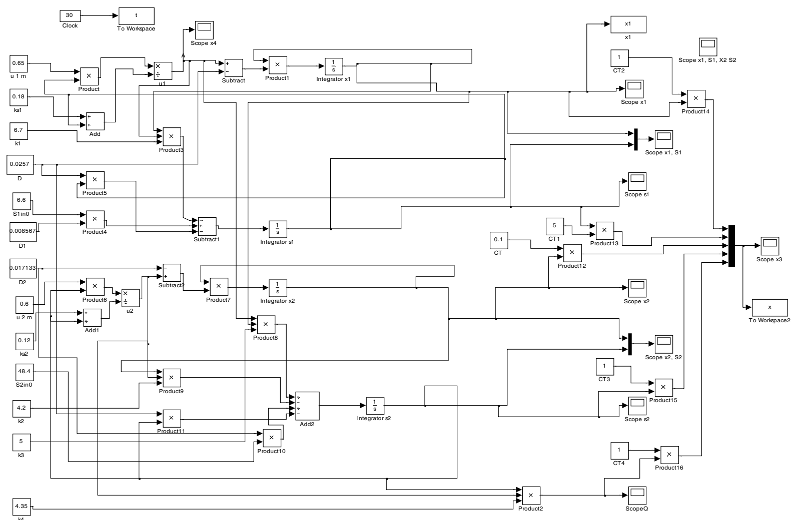

Fig. 1. The Simulink model.

When a 200% growth of the S1in0 concentration was considered a 135% increase in the biogas production was obtained. When considering these increases it must be taken into account that the organic content of the wastewater treatment sludge can only be increased by adding outer sources of organic matter. That process implies costs like acquisition, transportation, equipment for mixing matter with the sludge and others.

An important consideration is the evaluation of the consequences of the concentration growth on the other parameters, maintaining constant the other initial conditions.

The first observation is that the time necessary to obtain a maximum biogas production increases with one day in the first case and with two days for the latter one.

The values for the acidogenic substrate concentrations (S_1) remain below 1g/l in all three cases. The acidogenic microorganism’s concentration (X_1) grows proportionally to the microorganisms’ increase.

When it comes to the methanogenic bacteria, the growth is of 30% with each substrate enhancement.

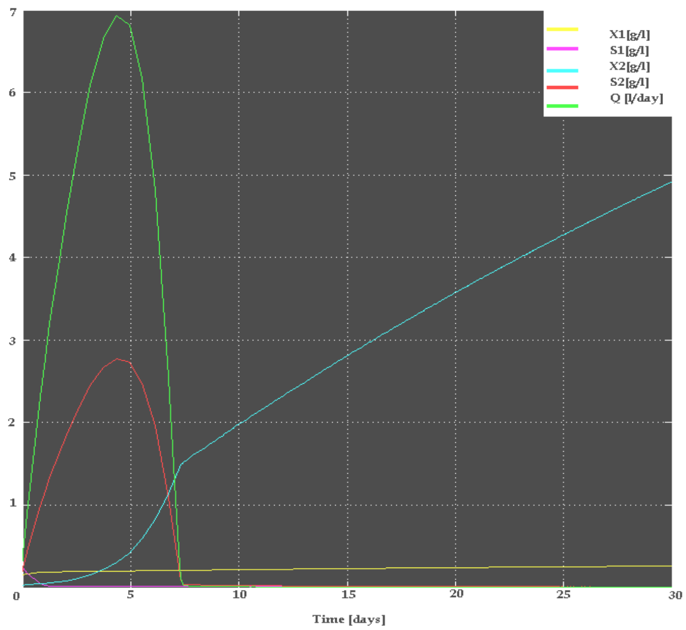

Fig. 2. Variation of X_1, S_1, X_2, S_2 and Q on a 30 day time period, Simulink results.

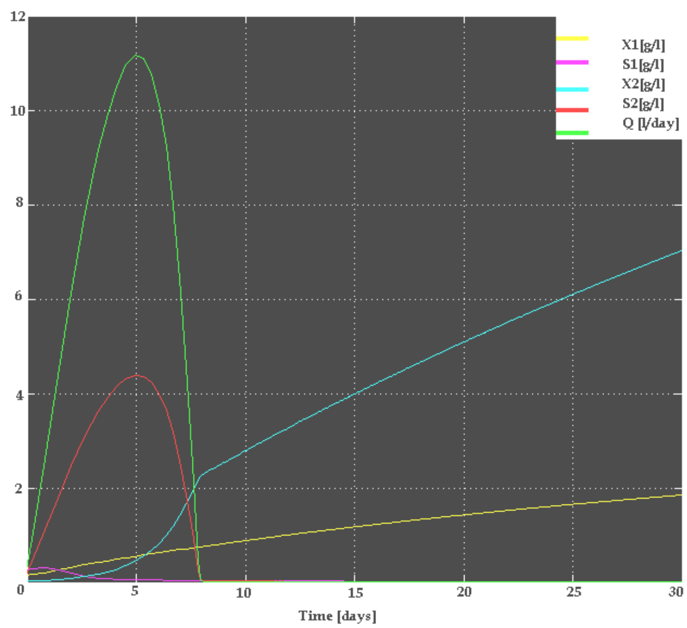

Fig. 3. Biogas production for S1in0 increased ten times.

4. Conclusions

The anaerobic digestion kinetics varies in large limits depending on the process conditions that are taken into account. The Simulink model can easily predict the process evolution but need a large volume of initial values, which can be difficult to obtain.

The increase of biogas production when modifying a model parameter (in this case the initial value of the substrate) is considerable, but the costs of this increment must be carefully estimated before considering this solution in an operating wastewater treatment plant.

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