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Mathematical modeling of anaerobic digestion processes and of photosynthetic growth of microalgae in photobioreactor. The establishing of the global mathematical model of the process

Abstract

The phase 2 of the project No. 269/2014 – BIOCON (*Mathematical modeling of anaerobic digestion process and of photosynthetic growth of microalgae in photobioreactor. The establishing of the global mathematical model of the process*) consisted in three activities, as follows: **Activity 1.1** – *Mathematical modeling of the photosynthetic growth process of microalgae in photobioreactor and its analysis through numerical simulation*, **Activity 1.2** – The establishing of the mathematical model of the anaerobic digester and its analysis through numerical simulation, **Activity 1.3** – *The coupling of the two models in order to obtain the global model of the biorefinary plant*. The three activities were fully realized and they are intended to analyze different mathematical model for each process and for the biorefinary plant. The models should express as accurate as possible the process dynamics and later will be used to design control algorithms.

Within the activity 1.1 the process of photosynthetic growth of microalgae in photobioreactor has been treated. Two mathematical models were investigated: 1. the mathematical model of the process of microalgae photosynthetic growth with light limitation; it contains three components: the model of radiative transfer, the biological model and the thermo-dynamic one. 2. Droop model in which the nutritional component is limited. Both mathematical models were analyzed through numerical simulation, as follows: the steady-state characteristics were determined and some possible operating regimes were established; every mathematical model was linearized in the chosen operating points and it was analyzed the possibility of reducing the mathematical model's order through the analysis of Hankel eigenvalues, considering all the interaction channels. Further on the properties of the linearized mathematical model were established. In the case of the first mathematical model of the process of microlagae photosynthetic growth it has been shown that the process model can be reduced from the 16^{th} order to the 3^{rd} order using only the low and medium frequency components of Bodel characteristics. The same analysis was done for the Droop model for which the interaction channel "the incident light intensity – intracellular substrate" was taken into consideration. The Hankel analysis concluded that the system order is equal to 2.

Within the activity 1.2 the digestion anaerobic process was treated. Two mathematical models were investigated using the same procedure shown before: ADM1 (Anaerobic Digestion Model no. 1) and a simplified model. ADM1 is a very complex model which contains 35 state equations that describe both biochemical processes and the physico-chemical ones. At the same time the model uses non-linear parameters and inhibitory terms in order to describe the reactions that take place in digester. The dynamics of the non-linear system of 35^{th} order was analyzed considering the channel inflow – methane concentration in gaseous state, multiplied by 10, in different operating regimes, defined by the average value of the inflow: 30, 70, 170 and 250m^3/day. It has been found the presence of some non-linearities which affect both the static gain and the properties of the dynamic regime (if the inflow has high average values the duration of the dynamic regime increase). In this case the analysis of Hankel eigenvalues suggests the

possibility of using a system of much smaller order than 35. Mathematical models of 12^{th} and 4^{th} were successively tested and it has been justified that the 4^{th} mathematical model can be used in satisfactory conditions in order to approximate the model in medium and low frequency areas of Bode characteristics.

Within the activity 1.3 the possibility to perform a coupling between an anaerobic digester and a photobioreactor in order to obtain a biorefinary plant has been investigated. It have been analyzed from an operating viewpoint three coupling schemes. The first scheme has been chosen because it has certain advantages and it also helps to the study of the processes aiming to obtain added values components. The coupling scheme consists in: the anaerobic digester inflow has a known composition (biomass, substrate, nitrogen, phosphorus etc.) being supplied from a municipal network or from an industrial operator. The effluent of the anaerobic digester having known properties can be discharged to a sewerage network if it respects the quality norms imposed by the law or to another treatment plant specified to the wastewater treatment processes. Following the anaerobic digestion of the organic wastes it results important flows of biogas that can be burned in cogeneration station in order to produce electrical energy, heat but high quantities of CO_2 too. In order to reduce the emissions of greenhouse gases in the atmosphere, the CO_2 produced through the combustion can be used as carbon source (substrate) in the process of microalgae photosynthetic growth. The microalgal biomass is processed in order to extract added value components and the resulted wastes represent an added substrate for the anaerobic digester for biogas producing. The dynamics of the nonlinear system was studied through numerical simulation. Further on the analysis of the global model has been done based on the procedures mentioned in the previous activities. The coupled dynamic system of 51th order has been linearized and then processed through Hankel analysis in order to reduce the order.