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Evaluation of co-digestion efficiency in two-stage systems with the use of a modified ADM1 model.

The increase in the consumption of fossil fuels associated with the growing demand for electricity has a negative impact on the natural environment. In this situation, searching for an alternative energy source is required – not only from an economic but also from an environmental point of view. The biogas from the anaerobic digestion of biomass in combination with other technologies can help in partial replacement of the energy from fossil fuels and reduce their environmental impact by introducing clean and decentralized renewable energy. Due to their characteristics, biogas plants meet the requirements for sustainable development. Biogas can be used for the production of combined of heat and power or purified to methane and injected directly into the gas network.

The main goal of this PhD thesis was to expand knowledge of the anaerobic digestion processes in two-stage fermentation systems fed by multisubstrates mixtures. In particular, it aimed to propose new, original feeding system into digesters, allowing stabilisation of digester parameters and increasing the biogas production. The purpose of the research conducted was to explain how substrates with different kinetic parameters for the hydrolysis stage can influence the anaerobic digestion process for multisubstrate mixtures. The proposed solution for the feeding system involved feeding a part of or whole substrate (or two substrates) directly into a methanogenic digester. The research considered the following substrates – maize silage, sugar beet pulp, fruit and vegetable wastes and whey. The studies were carried out by using an ADM1 model modified by the author, with parameters calibrated for each substrate. The simulation studies for co-digestion with use of two- and three substrate mixtures include the traditional and original feeding system and a gradual redirection of one or two substrates into the methanogenic digester. The redirection degree of 20%, 40%, 60%, 80% and 100% from the substrate stream was assumed. The simulation concerns different substrate ratio, i.e., 3:1, 1:1 and 1:30 based on the biogas production from each of feeding material. For comparison purposes, simulations involving redirecting of substrate with higher and lower kinetic parameters for the hydrolysis stage were performed. The analysis of the impact of redirecting substrates directly into the methanogenic digester focused mainly on fruit and vegetable wastes as well as whey. However, simulations consisting in redirecting of substrate with longer necessary hydraulic retention time were also done.

The first part of the thesis is dedicated to literature review, which serves as the introduction to the performed laboratory analysis and simulation studies. It contains the information about the anaerobic digestion process with a particular focus on improving biogas production methods, i.e., the two-stage fermentation process, co-digestion and substrates pre-treatment. The literature review also contains the information about performing dynamic simulations of biogas plant processes using the ADM1 model.

In the research part of this thesis, the results of the laboratory analysis and simulation studies for two- and three substrate mixtures in a two-stage fermentation system are presented. The results of the laboratory analysis, i.e., characteristic and biogas potential of the proposed feeding material, are discussed. The individual hydrolysis kinetic constants for each substrate and simulations of biogas potential tests with the use of a modified ADM1 model were performed. In the second part, the simulation studies for anaerobic digestion performed with the use of two- or three-substrate mixtures according to both the traditional and original system were performed. Biogas production and process parameters inside digesters (both acidogenic and methanogenic) achieved in the simulation studies are also compared in this part of the thesis. The model used takes into account new additional slowly and fast degrading fractions for carbohydrates, proteins and lipids, for each substrate individually.

On the basis on the simulation studies with a gradual redirection of one or two substrates into the methanogenic digester, it can be specified that with the special selection of the feeding materials, it is possible to improve biogas production by modifying the feeding system. When using substrates with different kinetic parameters for the hydrolysis stage, the redirection of the material with a shorter necessary hydraulic retention time into the methanogenic digester allows increasing biogas production and improving process parameters inside digesters. As research has shown, by using mixtures with similar kinetic parameters for the hydrolysis stage, the traditional feeding system ensures the highest possible energy gain. However, when a short hydraulic retention time is used in the biogas plant, introducing the proposed original feeding system may be necessary for stabilising parameters inside digesters and avoiding the inhibition of the anaerobic digestion process.

The most favourable impact of the original feeding system in the case of maize silage and whey mixtures was noted in a ratio of 3:1 (75% of biogas production from maize silage and 25% of biogas production from whey). For the mixture in this simulation scenario with 100% redirection of whey into methanogenesis digester, the observed increase of biogas was 5.97% with hydraulic retention time 35d, and 5.82% with hydraulic retention time 50d.