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EFFECT OF CORN STRAW PRETREATMENT ON EFFICIENCY OF BIOGAS PRODUCTION PROCESS - COMPUTER SIMULATION

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Anaerobic digestion is a natural process of organic material degradation by different kinds of microorganisms in the absence of oxygen. This process is used for industrial purpose to manage waste streams or to produce biogas. It gives a major contribution in reduction of harmful effects of organic waste disposal to the environment. The aim of agricultural waste pretreatment in biogas production is to decrease the retention time, improve utilization of raw material and improve the overall productivity and energy efficiency of the production process. In this paper the effects of combined chemical and mechanical pretreatment of corn straw biomass on biogas yield during anaerobic digestion of the feedstock were analyzed. The impact of pretreatment and process parameters in biogas production was analyzed by process simulation using the software SuperPro Designer. Using this tool, it was shown that alkaline pretreatment leads to an decrease of degradation time along with an increase in biogas yield.

Key words: biogas, anaerobic digestion, pretreatment, energy efficiency, SuperPro Designer

INTRODUCTION

Biogas is a colorless, non toxic gas, which is produced as an output of anaerobic digestion where complex and insoluble organic compounds are converted into simple and soluble organic compounds by anaerobic microorganisms [1]. It is a mixture of gases, mainly composed of methane (50-70%) and carbon dioxide (30-50%) with small amounts of water, nitrogen, oxygen, ammonia, hydrogen and hydrogen sulfide [2,3]. Produced biogas can be used to generate power and heat and also as a fuel for vehicles [4]. The composition and properties of biogas depends on the type of feedstock and process parameters. Every type of biomass containing proteins, fats, carboxydrates, cellulose and hemicellulose, could be a suitable substrate for biogas production, but the most commonly used are: animal manure, industrial waste, wastewater, waste sludge, energy crops, etc. [3]. The key consideration for choosing a feedstock is its sustainbility, biogas yield and price.

In recent years, energy crops, as a new category of raw materials, have been used exclusively for energy production, specifically biogas. Energy crops for biogas production should provide high energy levels, high biogas yield per hectare, contain little ash and lignin and should be easily transported and stored. Corn straw has almost all of these characteristics, and because of this, it is a suitable energetic crop for biogas production.

The annual production of biomass from agricultural wastes in Serbia is approximately 10,6 million tonnes of which corn straw is approximately 5,4 million tonnes [5].

There is a wide range of pretreatment technologies that can be used for biogas production, which have the same aims: rising in biogas yield, fastering anaerobic digestion and enabling a usage of local feedstock [6]. Pretreatment methods are especially useful in degradation of lignocellulosic materials that are rich in cellulose and lignin. Ideally, these pretreatment technologies should increase an availability of substrates for microorganisms and be cost efective [7].

Physical pretreatment disrupts the biomass structure, which increases specific surface area and reduces crystallinity. It can be done by milling, pyrolysis, ultrasound or radiation treatment, but this kind of modification causes high energy demands and results in high electric costs [8].

Chemical pretreatment is based on using various chemicals, mostly acids and bases (of different concentrations and under different conditions) in order to distrupt the biomass structure [6,9]. The addition of the chemicals causes cell wall breakdown and organic matter release from the cell. Oxidative degradation and acid/alkali hydrolysis are the most used methods of chemical pretreatment. The chemical pretreatment shortcoming is chemicals high cost, as well as the formation of waste streams which requires further treatment. This makes this pretreatment economically and environmentally unattractive.

Biological pretreatment of biomass structure is based on the enzymatic activity of microorganisms. This pretreatment can improve biogas production without energy supply. The general advantage of biological pretreatment is the possibility to take place at low temperature without using chemicals [6]. The disadvantages are that the process is time and space demanding, as well as the high cost of enzymes.

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Combining two or more pretreatments can increase biogas production, but it also raises the complexity and the cost of the process. Some of the most used combined pretreatments are steam explosion, extrusion, thermochemical pretreatment, etc.

Due to all of these facts, computer simulation can be an effective tool in the optimization of the biogas production process. Therefore, the aim of this paper was to simulate the biogas production process from corn straw as feedstock, using simulation software SuperPro Designer, which also represents the novelty of the paper. The simulation was performed in order to shorten the production process time, decrease the cost of the process, and increase the biogas yield.

THEORY AND METHODS

SuperPro Designer is a software package which enables the fast and cheap way to estimate the costs, product composition changes and possibilities for introduction of new technology. This program shortens development time, enables comparison of alternative processes and provides the opportunity to analyze more results in a short period. In this paper is used SuperPro Designer V.5.0..

Plant for biogas production has capacity of 800 t batch^{-1}. Composition of feedstock (corn straw) is given in *Table 1* [10]. The composition of corn straw depends on the type of corn, soil and time of ripening.

Table 1: Composition of corn straw

Component	Mass fraction, %
Lignocellulose	45.1
Cellulose	41.2
Minerals	6
Water	7.6

RESULTS AND DISCUSSION

In order to compare and evaluate the effect of pretreatment on biogas production, two scenarios were modeled: *Scenario A* without pretreatment and *Scenario B* with pretreatment. The scheme of main devices is shown on *Figure 1* and *2* [10]. In Scenario B, in addition to anaerobic digestion, pretreatment is performed in the fermenter (P-3/V-101).

In both scenarios, the substrate is prepared for degradation by chopping. If the degree of chopping increases, the degradation will also increase, but not necessarily the biogas yield. Chopping is performed in device P-1/SR-101 which capacity is 33 Mt h^{-1}. The chopped substrate at 25°C is transported by bucket elevator to a fermentor. Anaerobic digestion takes place in the fermenter (P-3/V-101), heating is performed with steam at 152°C. In Scenario B, in addition to anaerobic digestion, pretreatment is performed in the fermenter (P-3/V-101).

A detailed description of the operations and equipment used in both scenarios is presented in Table 2 [10].

Table 2: Information about operations and equipment

Operation	Equipment	Characteristic of process and equipment
Chopping / Cutting	Chopper P-1/SR-101	Capacity: 33 MT h^{-1} Final temperature: 25°C Power: 3 kW
Transport of raw material	Bucket elevator P-2/BE-101	Capacity: 33 MT h^{-1} Speed: 1m s^{-1} Height: 30 cm Length: 30 cm Power: 3.068 kW Height: 19 m
Anaerobic digestion	Fermentor P-3/V-101	Maximum volume: 1000 m^3 Outlet temperature: 37°C Maximum diameter: 7.33 m Height/Diameter: 2.5 Heating agent: Steam (152°C) Scenario A (total 21 days): Fermentation: The fermentation lasts 21 days Conversion of cellulose into biogas: 25.0% Scenario B (total 21 days): Pretreatment: The pretreatment lasts 7 days Type of pretreatment: Alkaline (6% NaOH) Conversion of lignocellulosic biomass into cellulose: 24.3% Fermentation: The fermentation lasts 14 days Conversion of cellulose into biogas: 25.0%

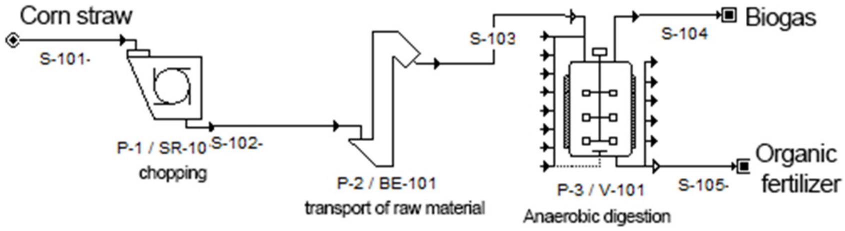

Figure 1: Scheme of main devices for biogas production without pretreatment - Scenario A

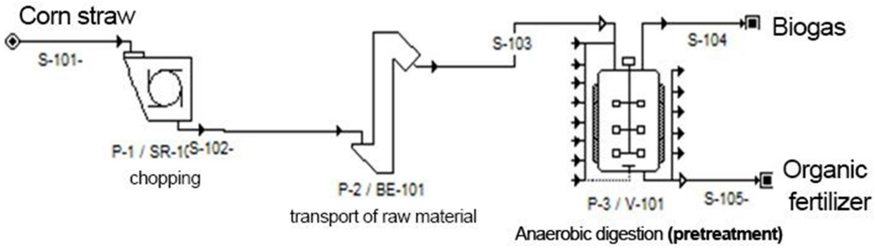

Figure 2: Scheme of main devices for biogas production with pretreatment – Scenario B

Anaerobic digestion in Scenario A lasts 21 days, converterting 25% of cellulose into biogas. Alkaline pretreatment is used in Scenario B, which enabled breakdown of lignocellulose and conversion into cellulose. Pretreatment with 6% NaOH lasts 7 days and during this time 24.3% of lignocellulose is turned into cellulose. After using alkaline pretreatment, anaerobic digestion lasts 14 days and 25% of cellulose is converted into biogas.

Flows of biogas production plants with capacity of 800 t batch^{-1} are given in *Tables 3 and 4* [10]. The input and output flows, the mass balance and the amount of biogas produced are also shown in the cooresponding tables.

The importance of pretreatment in biogas production can be seen from the results in *Table 3* and *4*. Based on the composition of the flows in the analyzed biogas production scenarios, it is observed that during pretreatment (*Scenario B*) a significant amount of lignocellulosic material is converted into cellulose.

Table 3: Composition of flow for biogas production without pretreatment – Scenario A

	Composition of flow		
	Input flow- Corn straw S-101	**Output flow- after fermentation**	
		Organic fertilizer S-105	**Biogas S-104**
Lignocellulosic biomass, %	45.1	45.0	
Cellulose, %	41.2	32.6	
Minerals, %	6.0	6.32	
Water, %	7.6	5.29	
Microbial biomass, %		10.8	
CO_2, %			49.0
CH_4, %			51.0
Mass balance, t batch^{-1}	800	758.8	41.2
Produced biogas			4.52 x 104 m^3

Table 4: Composition of flow for biogas production with pretreatment – Scenario B

	Composition of flow			
	Input flow- Corn straw S-101	**After alkaline pretreatment**	**Output flow- after fermentation**	
			Organic fertilizer S-105	**Biogas S-104**
Lignocellulosic biomass, %	45.1	34.2	34.0	
Cellulose, %	41.2	52.2	41.6	
Minerals, %	6.0	6.0	6.42	
Water, %	7.6	7.6	4.64	
Microbial biomass, %			13.6	
CO_2, %				49.0
CH_4, %				51.0
Mass balance, t batch^{-1}	800	800	747.8	52.2
Produced biogas				5.73 x 104 m^3

The increased amount of available cellulose led to an increase in biogas yield for approximately 27%. Obtained results are slightly lower than those in paper of Song et al. [11] where pretreatment of the corn straw by 6% NaOH results in aproximately 33% higher biogas production than the untreated sample.

CONCLUSION

The pretreatment of corn straw enabled about 10-11% more of the lignocellulosic material to be converted into cellulose, which significantly increased the amount of carbon that will be transformed in biogas during the anaerobic digestion. Biogas production in both scenarios lasts 21 days; *Scenario A* contains only anaerobic digestion, while the *Scenario B* comprises the biomass pretreatment of 7 days and the anaerobic digestion which takes 14 days. In addition, in *Scenario B*, where pretreatment was included, 27% more biogas was produced in comparison to *Scenario A*. Based on the obtained results it can be concluded that combined mechanical and alkaline pretreatment enhances the efficiency of the anaerobic digestion, which gives the possibility for further optimization of the process in order to maximize the biogas yields.

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