Optimisation tools for controlling biotechnological processes of biogas production

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Abstract. This paper considers the problem of increasing biogas production from biomass and waste. The purpose is to develop an electronic system for monitoring and controlling the processes of biogas generation under the condition of a lab. Creation of laboratory technological equipment that allows controlling process to obtain biogas as fuel. The equipment in addition to traditional metantanks with organic raw material contains an electronic system based on microcontrollers, sensors, and actuators allowing to achieve and keep maximum gas productivity. Creation of a software product and electronic system for optimal control of the biotechnologicl complex for production of high-calorie biofuels and electricity from organic waste are described. The advanced methods and technical solutions for solving problems of optimal control of biotechnological process of biofuel production from biomass and organic waste are used. The results are useful for solving the problem of renewable energy sources and improving ecological situation of the planet.

1. Introduction

Today, the world is widely assessing the possibilities of obtaining renewable energy sources from biomass, including from various organic wastes. Their energy potential in the world and in Ukraine is quite large, so scientists from many countries are increasingly paying attention to the development of appropriate technologies. It is obvious that bioenergy processes need to be effectively managed, and biogas technologies need to be optimized. On this basis, it will be possible to create efficient energy enterprises.

Scientists, engineers and technologists in the world are intensively conducting research on the intensification and optimization of the processes of obtaining renewable biofuels from biomass and organic waste [1], [2], [3]. Unfortunately, at present, such scientific developments in Ukraine are practically extremely limited [4].

The article considers the problem of creating laboratory technological equipment that allows to obtain energy (biogas, electricity), and the creation of software and electronic system for optimal control of the biotechnological complex of high-calorie biofuels and electricity from organic waste.

The subject of the research is the latest methods and technical solutions for solving problems of optimal management of the biotechnological process of biofuel production from biomass and organic waste, control and optimization of the quality and quantity of biofuels obtained in biotechnological processes.

The objects of research by and large can be called: electronic devices and their components, sensors, computer programs, mathematical models, laboratory systems for obtaining energy; biomass and waste and their utilization by conversion into environmentally friendly biofuels; assessment of the possibility of operation and use of biogas by aircraft engines to generate electricity.

More narrowly, the purpose of the study described in the article is to develop and create electronic and technological equipment and software that can be used to monitor and optimize, accelerate and control the biotechnological processes of gas biofuel production.

Research methods used in the work: microbiological, chemical-physical, biotechnological, mathematical, as well as methods of electronic cybernetics, programming, information theory, mathematical statistics, mathematical modeling, computer data processing, and methodological aspects of working with sensors.

Extraction of energy raw materials of traditional species is constantly increasing and leads to global warming. Raw materials are gradually depleted, which is especially noticeable at the regional level, including in Ukraine. This trend is also accompanied by environmental threats to the accumulation and pollution of ecosystems by various wastes, which is now global and increasingly uncontrolled. For example, modern aviation is one of the main consumers of petroleum fuels in the form of gasoline and jet fuels. Most of the civil aviation fleet is equipped with jet engines. During ten years (1992 - 2002) the level of fuel consumption for RDA increased by 21%. Aircraft are responsible for more than 2% of global CO2 emissions. In addition to CO2, aircraft exhaust gases contain a number of other components that negatively affect both human health and global climate change. By 2050, air transport will be the source of 20% of all harmful substances emitted in the world. In this regard, in recent years, the issue of greening the aviation industry has become quite acute, namely the reduction of greenhouse gas emissions such as CO2, CH4 and others, as well as reducing the toxicity of exhaust gases. One of the ways to solve this problem is to find and introduce alternative biofuels in aviation.

At the same time, the use of biotechnological approaches to obtain different types of fuel (solid, liquid, gaseous) from renewable raw materials and waste has long been known. The resulting energy products using such biotechnology are usually renewable, environmentally friendly as well as the technology itself.

Biogas is an analogue of natural gas, but unlike it, biogas is a renewable and environmentally friendly source of energy, because it is obtained from biomass, which in the process of its formation fixed atmospheric carbon dioxide, and hence this gas is neutral to the greenhouse effect. It consists of methane, hydrogen and carbon dioxide.

The raw materials for the production of methane and hydrogen can be a variety of organic residues: agricultural waste, waste food, textile and other industries, municipal waste, wastewater.

So today, in our opinion, the priority of further development and modernization of these technologies for biofuel production is also the development of electronic devices, mathematical models, applied computer programs to optimize the parameters of the technological process.

In this paper, we present the created hardware and software complex for managing biotechnological processes of processing biomass and waste into biogas.

2. Determination and analysis of the main parameters and conditions of biogas production from biomass and waste

This section consists of two non-equal subsections which describes chemical and electronic aspects of the process correspondingly.

2.1. Anaerobic decomposition of organic matter

Anaerobic fermentation, or more precisely methane fermentation, is the process of biodegradation of organic matter with the release of free methane [5]. One can write:

$$\text{Organic compounds} + H_2O \rightarrow CH_4 + CO_2 + C_5H_7NO_2 + NH_4 + HCO_3 .$$

There are 3 main stages of anaerobic decomposition of organic matter.

The first one is determined by the activity of microorganisms with active hydrolytic enzymes. They decompose complex organic molecules (proteins, lipids, polysaccharides, carbohydrates, fats) into simpler organic compounds. That is, the organic compounds that are present in biomass begin to break down into the simplest organic compounds (amino acids, sugars, fatty acids) under the action of hydrolytic enzymes. This stage is called hydrolysis and occurs under the influence of acetogenic bacteria.

Cellulose is a polysaccharide that is the main component of the cell walls of higher plants and algae. Its synthesis is superior to the synthesis of all other natural compounds, so that (along with starch) cellulose is the most common organic compound on Earth.

Eubacteria belonging to different taxonomic groups are able to decompose cellulose under anaerobic and aerobic conditions: individual members of the genus Clostridium, a number of actinomycetes, myxobacteria, some bacteria of the genus Pseudomonas, coryneform bacteria of the genus Cellulomonas, permanent inhabitants of the genus, Bacteroides, Butyrivibrio and others.

The second stage is associated with the activity of hydrogen-forming fermentors, the end products of metabolism of which are H2, CO2, CO, lower fatty acids (primarily acetate) and alcohols. Actually, at the second stage, a part of the simplest organic compounds undergoes hydrolysis oxidation under the influence of heteroacetogenic bacteria, as a result of which acetate, carbon dioxide and free hydrogen are obtained. The other part of the organic compounds with the acetate obtained in step 2 forms C1 compounds (the simplest organic acids). The resulting substances are a nutrient medium for stage 3 methane-forming bacteria.

Stage 3 takes place in two processes, caused by different bacteria. These two groups of bacteria convert stage 2 nutrients into methane CH4, water H2O, and carbon dioxide [5], [6].

The process takes place in bacterial biomass and includes the conversion of complex compounds - polysaccharides, proteins and proteins into methane, CH4 and carbon monoxide CO (4). One can say that methane-forming bacteria complete the anaerobic destruction of organic matter.

Methanogenic bacteria can have a temperature optimum of 25ºC, 30-40ºC, 55-65ºC, 55-97ºC. The optimum pH is 6.5 to 7.5. There are halophilic species with optimal conditions for growth at a content of 65 - 70 g / l NaCl in the environment.

The electronic control system should keep the parameters of the process in the framework of the required range of parameters.

2.2. Use of sensors and electronic equipment to control the biotechnological process

Most biogas plants have almost no automatic control over the process of biogas production and waste disposal. At the same time, there are new high-tech and relatively inexpensive capabilities for automatic analysis of the environment in the methane tank with software control for calorific gas biofuel, which will allow to obtain it in larger quantities per unit of raw material. In addition, this approach provides for more effective continuous environmental monitoring of processes occurring in the reactor area and beyond.

To create an automated system for managing a biotechnology complex, it is necessary to get acquainted with the requirements that may be imposed on it, as well as to consider options for the hardware base on the basis of which such a system can be created.

Electronic control systems for biotechnological processes are generally similar to the corresponding systems for automatic control of the environment in greenhouses. But the parameters controlled are different. The main purpose of automation of the biotechnology complex is to monitor various indicators of sensors and control the optimal conditions for living organisms that require a certain range of temperature, humidity, light, humidity and air composition (oxygen, carbon dioxide and nitrogen). Coverage helps control many of these factors.

It is necessary to choose the hardware base for the implementation of our system. There are different ways and technologies for this. These are microcontrollers, an open source Arduino platform used to create electronics projects, single-board computers.

A single-board computer is a full-fledged computer built on a single circuit board, with a microprocessor, memory, input / output (I / O) and other functions required for a functional computer. Single-board computers were created as demonstration or development systems, for educational systems, or for use as embedded computer controllers. Many types of home computers or laptops combine all their functions on a single circuit board.

Unlike a desktop personal computer, systems with single-board computers often do not have expansion slots for peripheral functions or devices. Single-board computers are built using a wide range of microprocessors. Simple designs, such as those created by computer enthusiasts, often use static RAM and inexpensive 8- or 16-bit processors. Other types, such as blade servers, work similarly to a server computer only in a more compact format.

Currently, the market is quite a lot of popular models from different companies. Some of the most popular (different models and variations): Raspberry Pi, BeagleBone, Orange Pi, Banana Pi, Asus Tinker Board. They all differ in price, specifications, design, etc. We decided to choose the leader in sales and popularity - Raspberry Pi, which has a relatively average price and performance compared to competitors, but at the same time has the largest community and open-source software.

The Raspberry Pi [7] is a tiny computer the size of a credit card, the board has a processor, RAM and the typical hardware ports that you will find on most computers. Raspberry Pi 3 (Figure 1) is the third generation. It replaced the Raspberry Pi 2 Model B in February 2016.

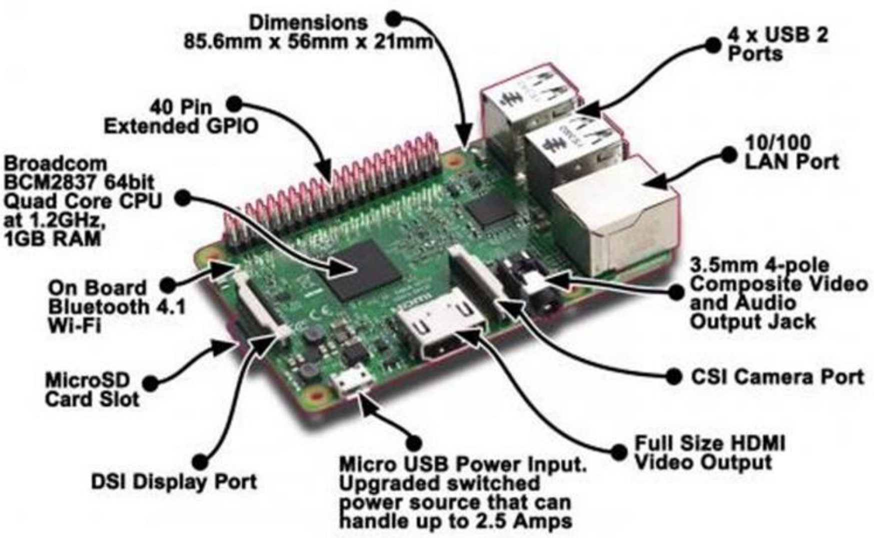

Figure 1. Raspberry Pi 3 model B [7].

Based on the review of possible solutions, it is necessary to make a choice to build a base for automation of the biotechnology complex. As technology moves in the direction of the Internet of Things, we also choose this vector. Among the main components of IoT lies hardware that supports all sensors and connected software. The most common hardware platforms for IoT are Raspberry Pi and Arduino, so we abandon the option with a "naked" microcontroller, because it is at least costly in terms of time and complexity of development. Actually, the initially low cost of the microcontroller may not compare with the additional server and client cost part in the future project.

For automation of a biotechnological complex first of all the data on the basis of which modules for creation of necessary conditions of a microclimate will be included are required. To do this, we need various sensors, as well as other equipment, such as an analog-digital transmitter for connecting analog sensors.

2.3. Sensors

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Different peripherals may be responsible for the management of the biotechnological complex, and to be precise, for the creation of the desired microclimate, depending on the necessary requirements and financial capabilities. This subsection explains the sensors used in our project, as well as possible options for creating the necessary conditions through automation to create a microclimate in the biotechnology complex.

There are many sensors that can be used in the system. Some examples of the sensors by purpose:

• Pressure sensor to detect physical pressure, e.g. during compression, shocks, etc.

• Photocells for measuring the level of illumination, detection of a simple object on the principle of light / dark

• Temperature sensor for environmental temperature control, liquid, biomass mixture.

• Vibration sensor for motion / vibration control and orientation, for example when mechanically exposed to a mixture.

• IR receivers - used to detect infrared signals from the remote control.

humidity sensors.

All sensors have their own methods of interaction and may need some interface. Some of them can be simply connected to the board, while connecting others requires additional manipulation. For example, resistors or additional power supplies may be required.

The sensors differ in the type of output signal: analog or digital.

When choosing sensors, one can see that in a description the compatibility with Arduino is most often mentioned and compatibility with Raspberry Pi is not mentioned. If the sensor emits a digital signal, it can be connected to Raspberry Pi GPIO ports. If the sensor emits an analog signal, one can connect such a sensor directly to the Raspberry Pi only with an analog-to-digital converter (ADC), which is often included in the Raspberry Pi expansion card.

Different sensors can vary greatly in price; the cost of the sensor can be $1 or $5, sensors with very high accuracy of signal detection can be much more expensive.

The following is the list of our selected sensors for monitoring the performance of the biotechnology complex and a description of what they measure.

Digital sensors:

• AM2320 [8] for humidity and air temperature;

• BH1750 [9] for room lighting;

• BMP180 [10] for temperature and air pressure (the second we are interested in the first place, because other sensors are used to measure temperature);

• DS18B20 [11] for soil temperature.

Analog sensors:

• MQ-2 Gas Sensor [12] for gas leak detector;

• Moisture Sensor [13] for soil moisture.

Since the Raspberry Pi does not have analog inputs, you may need an analog-to-digital converter, which acts as ADS1115 [14].

3. Design Solution of the Developed Software

Once we have identified our sensors and devices, connected them to the Raspberry Pi, tested to use them (read readings, send signals to the relay), we need to create a system that will combine all these devices and scripts to them, create the necessary microclimate conditions by sending control signals to peripherals and output information to a user interface to which one wants to have remote access.

To do this, one can organize the server on another device (PC) or rent it from a third party, and then send it from our Raspberry Pi, followed by processing on the server and output it to the user interface using the classic methods of organizing a web application using programming.

However, this will incur both additional costs and additional difficulties with setting up the server and client part, because to build a high-quality and functional web application one need to use many technologies and programming languages.

Another way is to organize the server on the Raspberry Pi itself, because it has a Linux distribution that allows you to use it as a full-fledged computer. We can install popular servers, such as Apache, which can output HTML files (via HTTP), and if you connect additional modules to it, it will be able to display dynamic web pages, using scripting languages such as PHP. Or we can use frameworks, such as WebIOPi. It was specially designed to work with GPIO ports Raspberry Pi and allows you to create a variety of custom applications.

After combining our devices into a single system, it is necessary to implement algorithms to automate the process of managing the biotechnology complex. These algorithms must be selected individually for specific tasks.

The work uses a computer program in Python, which is used to monitor, process information from sensors, control the biotechnology complex and transfer information for display in graphical form. The program receives data from sensors, processes indicators, performs calculations and displays the required parameters.

The hardware created in the work (Figure 2) consists of a microcontroller that controls the external peripherals and receives data from sensors.

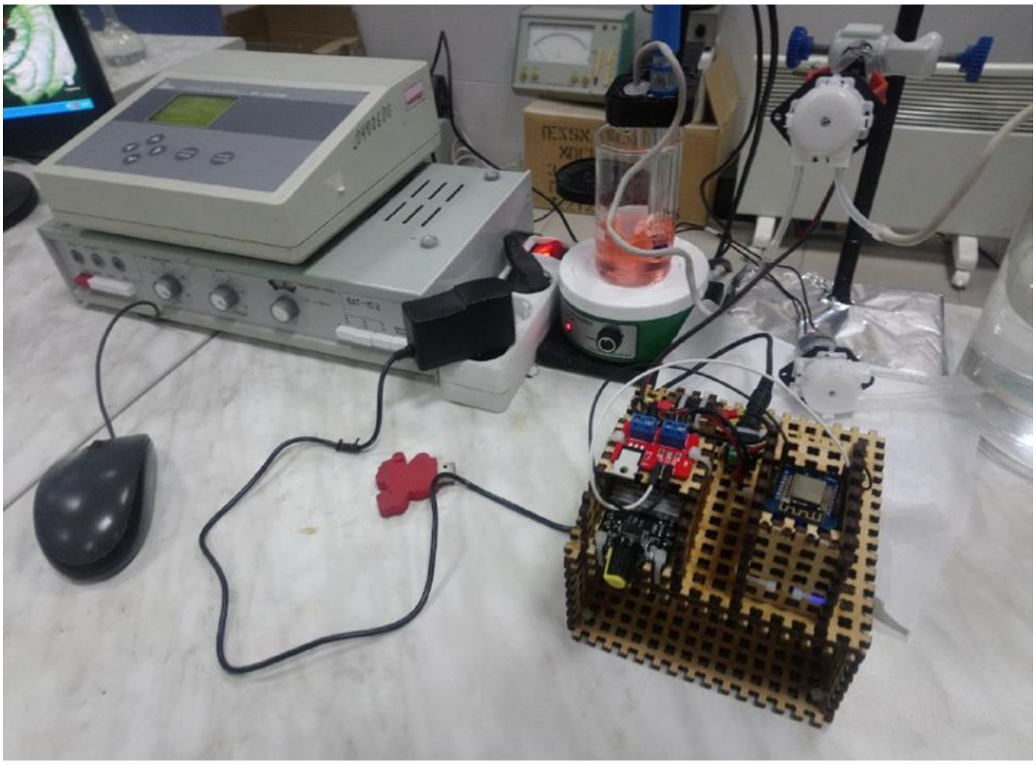

Figure 2. Hardware for experiments in the biotechnology laboratory.

Interaction with the device is via Wi-Fi. The device does not require an Internet connection, as it is a Wi-Fi access point. The device implements a server that implements software for interaction with the user. The device has a power supply of 12V for motors, 5V and 3.3V for the microcontroller. Wi-Fi operates at 2.4GHz.

The result of this work is the construction of an automated system with a web interface by combining programming languages Python, Javascript, PHP, HTML, IDE and based on Apache server, Ajax technology, jQuery libraries, DHT22, pigpio, urllib3, RPi.GPIO.

Conclusions

As a result of the research the following results have been obtained:

- the possible potential for biomethane production as an environmentally friendly fuel in Ukraine is presented;
- the main microbial cultures that are part of methanogenic associations that are able to transform biomass and organic waste into biogas are presented;
- analysed the feasibility and possibility of using sensors and electronic equipment for the analysis of basic substances entering the bioreactor, the environment in the bioreactor area, the quality of fuel biogas to be supplied to consumers as energy;
- developed, created and tested a laboratory installation to provide the biotechnological complex with sensors, electronic equipment, software for the cultivation of microbial cultures of methanogenic association;
- work was carried out on the docking of sensors with the control elements of the biotechnological complex for the production of biogas from organic waste.

The laboratory installation is suitable for controlling biotechnological processes of biogas production from biomass and waste with the subsequent optimization of processes.

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