POWER MACHINERY

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SMALL-SCALE BIO GAS COMBINED HEAT AND POWER PLANT WITH BIOCHAR CATALYST

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Abstract—*Alternative energy sources allows to replace traditional fossil fuels and firewood. However the most widely used wind and solar power plants can not provide constant power generation due to multiple factors that makes necessary to develop new types of power sources and to to improve efficiency of already existing ones. One of such energy sources are bio gas-fueled power plants which allow to combine the power generation and organic waste disposal functions. Efficiency and quality of bio gas production in such facilities can be significantly increased by using different catalysts such as biochar. A brief analysis of biochar production usage perspectives was held which showed that it can be used in different applications and can significantly increase efficiency of different technological processes. The influence of biochar on the biogas production processes was studied. The structure of bio gas-fueled heat and power plant with local bio gas generation was proposed.*

Index Term—Biochar; biogas; combined heat and power plant; small-scale power plant.

I. INTRODUCTION

Alternative energy is a set of perspective forms of energy production, transmission and use that are not as common as traditional ones, but are of high interest due to their cost-effectiveness and generally low risk of environmental damage.

Energy is the basis for all processes in all sectors of the national economic sector, the main condition for creating wealth and improving people's living standards. Today, energy is the most important driving force behind global economic progress, and the well-being of billions of people on the planet directly depends on its condition. The constant increasing number of people leads to an intensification of energy consumption. And if we don't develop alternative energy, it could lead to an energy crisis.

The problem of replacing traditional hydrocarbon energy sources such as coal, oil and gas is becoming more and more actual [1] year by year.

In addition to the possibility of depletion of traditional sources, there is also an environmental problem, as the combustion of hydrocarbon fuels leads to harmful emissions into the atmosphere, worsens the human habitat and creates environmental problems.

The way to solving environmental and energy problems simultaneously is to use biogas produced from agricultural and food waste as an energy source. The use of biochar as a catalyst in the anaerobic fermentation process can significantly improve the quality of biogas.

II. PROBLEM STATEMENT

To achieve a reliable and sustainable power supply, it is necessary to create a decentralised generation system that would include a large number of small-scale power sources instead of large centralised power plants. Small biogas-fuelled power plants can be a relatively compact solution.. Biogas can be produced directly at power plants from food waste or from waste from nearby agricultural enterprises.

Increasing the efficiency of biogas generation and quality is possible by using biochar as a catalyst for gas formation processes.

Therefore, to solve this problem, it is necessary to create an autonomous power plant with local generation of biogas fuel.

III. PERSPECTIVES OF BIOCHAR PRODUCTION AND USE

Biochar is a product obtained by the thermal decomposition of organic matter in an inert environment with negligible or limited oxygen. This process is called carbonisation. Biochar can have different properties and modifications, which are achieved by adjusting the temperature and heating rate, as well as by adding certain phases after or during the carbonisation process (e.g. activation). The properties are modified to satisfy the needs of different end-users, which leads to the many names for biochar on the market (e.g. biochar, activated biochar, biochar, etc.). We define biochar as all types of carbonised biomass, regardless of its end use, but excluding torrefied biomass, charcoal, and mixtures of carbonised biomass with fossil coal..

Biochar can be produced through thermochemical conversion processes called pyrolysis and hydrothermal carbonisation, as well as thermal gasification. Slow pyrolysis is the main production method. During the primary pyrolysis reaction, biomass is decomposed into bio-raw materials, which are then separated into bio-oil (resins) and aqueous phase, charcoal and non-condensable gases (syngas). The higher the production temperature, the lower the coal yield, even if the quality is higher. In order to produce activated biochar, the process is carried out either with main activation or with a separate, so-called physical or chemical activation..

The production of a tonne of biochar requires about three tonnes of dry matter. Any type of organic biomass can be used, but the most commonly used feedstock is wood biomass.

Humanity is constantly on the lookout for ways to reduce emissions into the atmosphere, which have been the main cause of climate change and global warming around the world. Every year, billions of tonnes of different types of biomass are produced around the world, which can be used in the manufacture of products and materials that can help mitigate the effects of climate change. Biomass is organic material from wood, crops, plant, animal and human waste. One of the ways in which organic biomass can be used is by heating it under anaerobic conditions. The process is called carbonisation, and technically it is the thermal decomposition of biomass in an inert environment with little or limited oxygen supply (pyrolysis). The products obtained include a gaseous product (syngas), a liquid phase (biochar slurry) and charcoal, which is formed with a certain amount of excess energy (heat).

Until recently, biomass carbonisation was mainly thought of as producing charcoal, which has long been used for heating and cooking (as well as in metallurgy and other industries). Today, the technology has improved significantly to enable the production of other charcoal products such as biochar, activated biochar or biocoal. The products are delivered together with the aforementioned biochar slurry, which is automatically separated into a high energy dense liquid (called "bio-oil") and an aqueous phase containing water and chemicals. The non-condensed gases are called synthesis gases, which contain H_2 and CO.

The properties of coal, and therefore its type, depend on the production conditions (temperature and heating rate).The properties can be modified either in the main carbonisation process by changing the heating time and temperature or by adding steam, or in separate post-carbonisation processes to meet the needs of different users.However, there may still be several product definitions in the literature, depending on the target audience and end use. For example, carbonised biomass intended for soil improvement, fertiliser and/or animal feed is often referred to as biochar, for adsorption materials as activated biochar, for industrial uses such as metallurgy as biochar (or biocoke).The aim was to distinguish between fuel and non-fuel applications of charred biomass. In general, it is the same product from the same basic process, which can be modified in accordance with requirements.

The production of carbonised biomass, or biochar, involves two main thermochemical conversion processes [3] – [5]: pyrolysis and hydrothermal carbonisation. Thermal gasification can be considered as a third carbonisation process, but its main product is syngas, so it is not considered here.

Among all pyrolysis processes, there are two main technologies: slow and fast pyrolysis. The former is a proven thermal method for converting biomass into biochar. The gases can be condensed to produce bio-oil (coal slurry) and / or non-condensable gase (H_2, CO), which in turn can also be directly used for energy production through combined heat and power plants (CHP).

The process can use low or high temperatures with little or no oxygen. Conventional slow pyrolysis can produce high quality char using relatively low temperatures and low heating rates. The residence time of the steam can be around 5-30 minutes. The volatile organic fractions present in the vapour phase continue to react with each other to form char and some liquid fractions. Fast pyrolysis was developed mainly for biomass liquefaction, so it is not considered here.

There are many applications for biochar. According to a study by Hans-Peter Schmidt [6], there are 55 different potential applications. The carbon content of biochar is relatively stable, and thus biochar was originally proposed as a soil amendment to store carbon and improve soil conditions, a nutrient and microbial carrier, and an immobilising agent for the remediation of toxic metals and organic contaminants. Due to the optimisation and improvement of production processes, as well as the need to reduce carbon emissions from other business sectors, other applications are now also available, such as use as a catalyst for industrial applications, as a porous material to mitigate odours, as a feed additive to improve animal health and nutrient uptake and therefore productivity, etc.

Despite its multifunctionality, all types of biochar use can be grouped according to the following features:

- soil enrichment;
- animal breeding;
- adsorbtion applications;
- industrial production;
- energy and other production.

IV. Biochar Influence on Biogas Production

One of the most common methods of biogas production is anaerobic digestion (Fig. 1). The adding of biochar to this process allows to increase the level of alkalinity and pH of the solution, which reduces ammonia inhibition and acid stress for the microbial colony. The porous nature and large specific surface area of biochar can facilitate the colonisation of bacteria and archaea, which leads to improved anaerobic digestion performance [7]. A large number of surface functional groups and good electrical conductivity of biochar can increase methane yield through direct or indirect electron transfer mechanism among anaerobic microbes [8].

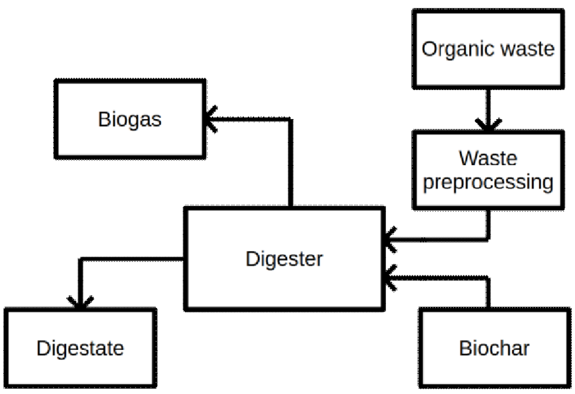

Fig. 1. Anaerobic digestion process

The properties of biochar can promote the formation of microbial biofilms (improves methanogen colonisation) and adsorption of inhibitors such as NH_3 and acetate [9]. In the anaerobic digestion process, biochar is also used to create a microbial protective layer that stimulates the production of CH_4. Biochar also acts as a stabilising agent, controlling the access of nutrients to the bacteria and removing volatile fatty acids and NH_3 after addition to a digestate with a high solids content [10].

Food and agricultural waste can be used for biogas production. The approximate amount of biogas produced per tonne of waste is shown in Table I.

TABLE I. APPROXIMATE VOLUMES OF BIOGAS PRODUCTION

No	Type of raw material	Volume of biogas production, m^3/tonne	
		Without biochar	***With biochar***
1	Greens	290–490	377–637
2	Beet tops	75–150	97–195
3	Molasses	up to 630	up to 800
4	Fruit or vegetable pulp	108	140
4	Beer grains at 75% moisture	138	173
5	Barda	40–50	52–65
6	Food waste	about 100	about 128
7	Fat	1300	1664
8	Pig manure	340–580	435–740
9	Bird manure	310–620	400–800
10	Horse dung	200–300	260–390
11	Cow dung	300–450	380–570
12	Sheep dung	300–620	380–790

The data in the table shows that the addition of biochar as a catalyst for the anaerobic digestion process can increase the amount of biogas produced by up to 30%.

V. Electrical Power Production

Electricity production from biogas is still relatively new in the world, but in industrialised countries this application is more widespread. Due to the environmental impact of fossil fuels, the use of biogas for power generation, such as gas turbines of various capacities and use as fuel in internal combustion engines, is becoming more widespread [11].

The European Union has assumed that most of the energy production can be provided by biogas sources, so its consumption in energy production is likely to increase.

The content of CO_2 and N_2 в in biogas affects its energy efficiency. To improve it, a number of technologies have been developed to modernise biogas by removing pollutants from it [12].

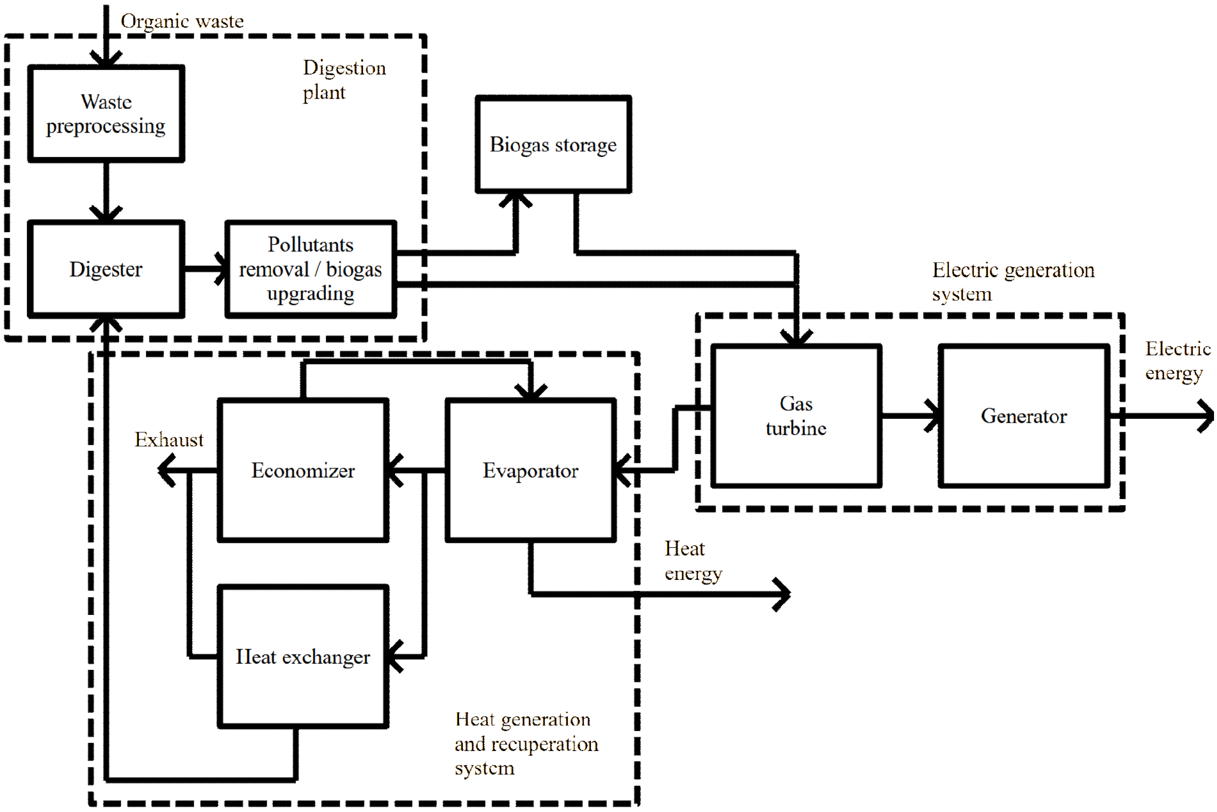

Fig. 2. Block diagram of a power plant

These technologies include chemical purification, membrane separation, pressure fluctuation absorption, and pressurised water purification. The simplest and cheapest is the pressurised water technology, which ensures low CH_4 loss during the process and allows for efficient hydrogen sulphide removal.

The energy efficiency of the selected biogas treatment technology [12] can be determined by the following expression:

$$\eta_i = \frac{Q_{\text{out.prod}}}{Q_{\text{in.feed}} + Q_{\text{in.utility}} + \dfrac{E_{\text{in.el}}}{\sigma}}, \quad (1)$$

where $Q_{\text{in.feed}}$ is the lower heat value of the input gas; $Q_{\text{in.feed}}$ is the lower heat value of the produced gas (MWh); $Q_{\text{in.utility}}$ is the required amount of heat for solvent regeneration, heating and condensation (MWh); $E_{\text{in.el}}$ is the amount of electricity required to power the process equipmen; σ is he efficiency of converting steam into electricity.

To generate electricity, a combined heat and power (CHP) plant based on a gas turbine unit with biogas generation by anaerobic digestion is proposed, the structural diagram of which is shown in Fig. 2

The power plant consists of a biogas generation unit, where organic waste is prepared, anaerobic digestion and biogas purification is carried out, a gas turbine power generating unit and a heat generating unit. The heat generating unit includes an evaporator to supply steam to heat consumers, a heat exchanger to supply the necessary heat energy to support the anaerobic digestion process and an economiser to generate additional heat energy from the turbine exhaust..

The energy efficiency of the system is defined as [12]:

$$\eta = \frac{W_{\text{out}}}{Q_{\text{in.biogas}}}, \quad (2)$$

where W_{out} is the output power of the installation (kW); $Q_{\text{in.biogas}}$ is the initial heat input rate to the biogas system (kW), which can be calculated as:

$$Q_{\text{in.biogas}} = m_{\text{biogas}} E_{\text{LHV}}, \quad (3)$$

where m_{biogas} is the biogas mass flow rate (kg/s); E_{LHV} is the energy required to heat it to the minimum required temperature.

The ability to use biogas as a fuel for combined heat and power generation allows achieving the highest energy efficiency.

V. CONCLUSIONS

The ability of biogas as a fuel for generating electricity and heat is promising, as food and agricultural waste can be used to produce it, which will simultaneously solve the problem of their disposal. At the same time, it is advisable to use the anaerobic digestion method to produce biogas. The waste resulting from this process can be reused as fertiliser for agriculture.

Building a power system based on the principle of distributed generation will increase the reliability and resilience of the power system to natural and technological threats.

The addition of biochar as a catalyst for the anaerobic digestion process allows to increase the quantity and quality of biogas produced, which has a positive impact on the overall energy efficiency of the power system.

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М. П. Василенко. О. С. Баранова. Маломасштабна біогазова тепло-електростанція з біовугільним каталізатором

Альтернативні джерела енергії дозволяють замінити традиційне викопне паливо та дрова. Однак найбільш широко використовувані вітряні та сонячні електростанції не можуть забезпечити постійне виробництво електроенергії через численні фактори, що вимагає розробки нових типів джерел енергії та підвищення ефективності вже існуючих. Одним із таких джерел енергії є електростанції на біогазі, які дозволяють поєднувати функції виробництва електроенергії та утилізації органічних відходів. Ефективність і якість виробництва біогазу на таких установках можна значно підвищити за рахунок використання різних каталізаторів, наприклад біовугілля. Проведено короткий аналіз перспектив виробництва та використання біовугілля, який показав, що воно може бути застосоване у різних сферах та дозволить значно підвищити ефективність різноманітних технологічних процесів. Досліджено вплив біовугілля на процеси виробництва біогазу. Запропоновано структуру біогазової теплоелектростанції з локальною генерацією біогазу.

Ключові слова: біовугілля; біогаз; тепло-електростанція; мала електростанція.

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Напрям наукової діяльності: відновлювальні джерела енергії, оцінка властивостей речовин та матеріалів за власними електромагнітними випромінюваннями.
Кількість публікацій: більше 40 наукових робіт.
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