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Performance Characteristics of Biogas Device and Prospects of its Application in Agriculture

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ABSTRACT: The article describes the introduction of biogas plants in agricultural production. To determine the profitability of biogas plants, data are provided to calculate the potential of biomass: organic waste from settlements; animal waste; poultry waste; crop waste; waste from the processing industry. Graphical dependencies on the livestock and poultry population per day, as well as on the amount of sunflower, rice and sugar beet were obtained. There is also a table of thermophysical properties of organic waste of agricultural production, which makes it possible to increase the efficiency of calculations to determine the resources of biomass. The basic diagrams of a biogas plant, a gas turbine power plant and a steam turbine power plant are considered and their operating characteristics are disclosed. To improve the operational and technical characteristics of biogas plants intended for power generation, it is proposed to use contactless generators in their design and stabilize electrical parameters using a direct-acting frequency converter. The advantages and disadvantages of biogas, as well as the directions of its effective use, are described.

KEYWORDS: biomass, organic waste, biological fertilizers, cogeneration, steam turbine, hydrogen sulfide, ammonia, nitrogen oxide, beet syrup, gas turbine, homogenization, pumping station, condenser.

I. INTRODUCTION

Today, humanity uses raw materials from the bottom of the planet (oil, gas, coal, etc.), the processing of which provides energy used in various areas of our activities. However, it is known that the resources of conventional fuel are limited, in addition, the use of traditional energy has a negative impact on the environment [1, 2].

Currently, most of the small biogas plants are located in China. At the end of 2010, there were about 40 million biogas plants in operation in China, producing over 10 billion m3 of biogas per year. There are over 5 million small biogas plants in operation in India today. The total (theoretical) potential of the biogas industry in Germany will reach 100 billion kWh by 2030, which is about 10 per cent of the country's energy consumption. The theoretical potential for biogas production in Russia is 70 billion m^3 per year or about 110 billion kWh of electricity. Biogas contains 60-70% methane, 30-40% carbon dioxide, a small amount of hydrogen sulfide, a small amount of a mixture of hydrogen, ammonia and nitrogen oxides. At the same time, 1 m^3 of biogas is equivalent to 0.8 m^3 of natural gas, 0.7 kg of fuel oil, 0.6 litres of gasoline, 1.5 kg of firewood. 1 m^3 of biogas from a cogeneration plant can produce 2 kWh of electricity.

II. MATERIALS AND METHODS

To determine the economic efficiency of a biogas plant, it is necessary to calculate the resources (potential) of biomass: organic waste of settlements; animal waste; poultry waste; crop waste; waste from the processing industry.

The organic waste of settlements includes municipal solid waste and wastewater (WWS) [1].

Livestock waste.

When determining stocks of animal waste, the following should be considered:

for cattle - 30 kg per day with a humidity of 85%;

for pigs - 4 kg per day, humidity 85%;

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For small ruminants - 4 kg per day at a humidity of 70%.

The calorie content of 1 kg of dry manure is 2000 kcal. Table 1 shows the total energy potential of 100 head of cattle per day. Taking into account the data in Table 2, it is possible to determine the energy potential of a livestock enterprise by the number of heads.

Table 1. The total (theoretical) energy potential of animal and poultry waste per 100 heads per day

Livestockwaste	kcal	kg u.t.	kWh
Cattle	$6 \cdot 10^6$	857	6957
Sheep	$7 \cdot 10^5$	100	813
Pig	$8 \cdot 10^5$	114	927
Chickens	40000	5,7	46,4
Broilers	30000	4,3	35

Figure 1 shows a graph of the dependence of electricity produced per day on the number of cattle, pigs, and poultry.

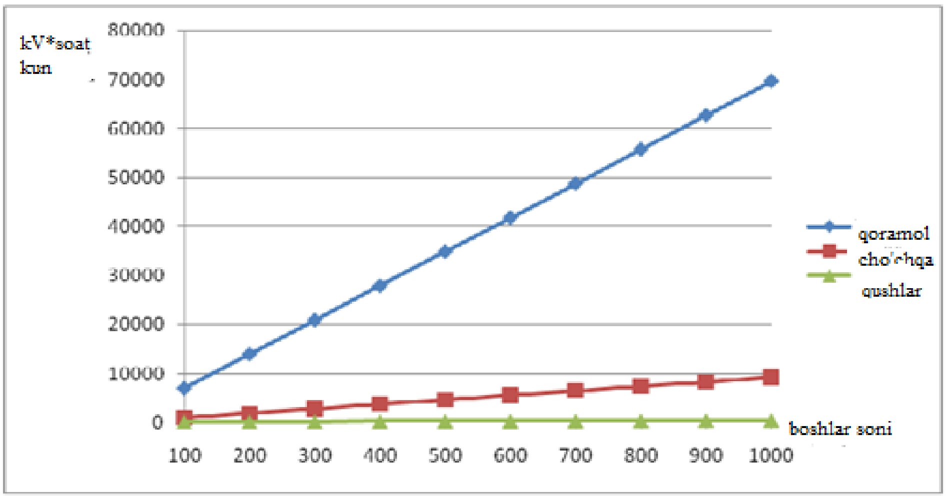

Figure 1. Dependence of electricity produced per day on the number of livestock and poultry

Poultry waste.

The amount of manure per poultry is determined at a moisture content of 75% according to known zootechnical data:

- 0.2 kg per day for laying hens;

- 0.115 kg per day per broiler (from 0.2 kg to 1.5 kg of live weight 42 - 45 days of obesity).

The calorie content of 1 kg of dry manure is 2000 kcal. The total energy potential of poultry waste is calculated for the entire livestock. At the same time, up to 73 kg of manure at 75% humidity and 42 kg of manure per broiler at the same humidity are collected per chicken per year. Table 2 shows data on the total energy potential of 100 heads of poultry waste per day. Waste from crop production. It is known that plant waste includes waste from the production of legumes, organic waste from the production of potatoes, sugar beet, sunflower and vegetable waste. Waste from the production of leguminous crops is accepted taking into account the moisture content of 15%, taking into account the ratio of straw or stems (corn, rice, etc.) And grain 1 ... 1.5: 1.

However, the calorific value of 1 kg of straw or stem is 3500 kcal.The total potential of leguminous waste is equal to the technical potential and is determined taking into account the annual yield for all categories of farms.The economic

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potential is 50% of the gross and technical potential. In the production of potatoes, vegetables and sugar beets, the mass of organic waste (tops) is from 30% to 50% of the yield, the moisture content is 65%.However, the calorie content of 1 kg of dry hemp is 2000 kcal. The total capacity of potato and vegetable waste is equal to the technical capacity and is calculated for the annual harvest of potatoes and vegetables for all categories of farms, including subsidiary farms. The economic potential is that large agricultural enterprises do not exceed 7% for potatoes and 20% for vegetables. Table 3 shows data on the total energy potential of plant waste per 100 kg of dry raw materials.

Table 2. Gross (theoretical) energy potential of plant waste per 100 kg of dry raw materials

Vegetablewaste	ккал	кг у.т.	кВт·ч
Straw and stems (cereals and legumes)	350000	50	407
waste of potatoes, vegetables and sugar beets	350000	50	407

Figure 2 shows a graph showing how much electricity can be produced depending on the amount of sunflower, rice and sugar beet.

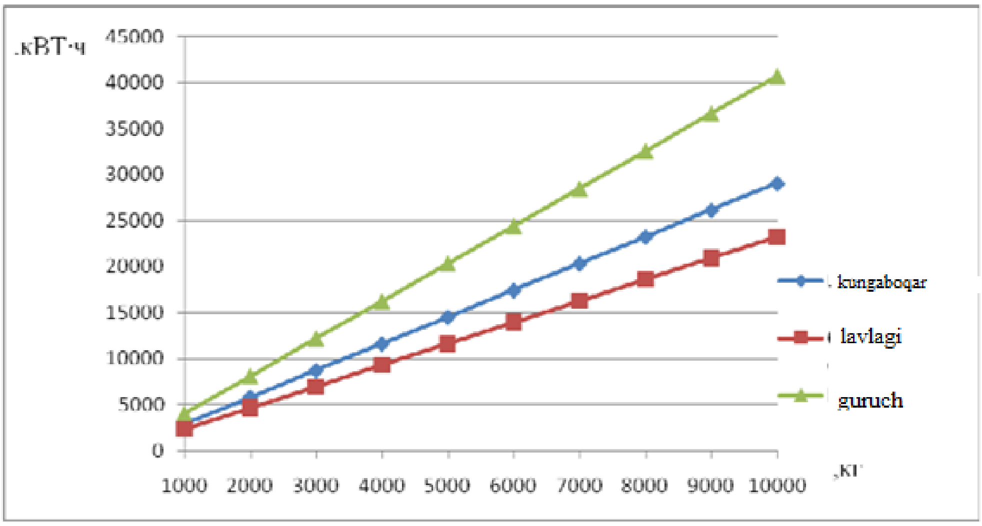

Figure 2. Dependence of the generated electricity on the amount of sunflower, rice and sugar beet

Waste from the processing industry.

Organic waste (husk) of the oil industry makes up 20% of the seed yield with a moisture content of 15%. The wastes in the production of beet sugar are beet pulp and beet molasses. The yield of this waste is 5% of the weight of each processed beet. The calorie content of beet pulp is 2500 kcal/kg, molasses - 4000 kcal/kg of sugar, the amount of sugar in molasses is 70%, humidity is 30%.The processing of organic waste flour and grain products in industry can be up to 25% with a moisture content of up to 15%.The calorie content of such waste is 3500 kcal .It is known that when poultry is processed, there is usually no waste. When processing cattle, pigs and small ruminants, organic waste can be up to 16%, the moisture content is 70%.Table 4 presents data on the total energy potential of the processing industry per 100 kg of raw materials. Table 5 provides information on the thermophysical properties of organic waste in agricultural production, taking into account zootechnical standards and thermophysical properties of physiological waste.

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Table 4 - Gross energy (theoretical) potential of the processing industry per 100 kg of raw materials

Waste from the processing industry	ккал	кг у.т.	кВт·ч
Oil mill (crust), grind flour	350000	50	407
Alcohol (inkind)	200000	28,6	233
Meatprocessing	250000	35,7	290

Table 5 - Thermal properties of organic agricultural waste

Type of organic waste	Waste management standards	Calorific value, kcal per 1 kg of dry weight	Waste moisture
Livestock waste (per head): 1) cattle 2) sheep 3) pigs	30 kg per day 4 kg per day 4 kg per day	200020002000	85% 70% 85%
Poultry waste (per piece): Chickens Broilers	0.2 kg per day 0.115 kg per day	20002000	75%75%
Types of organic waste	Waste production norms	Calorific value, kcal per 1 kg of dry weight	Waste moisture
Crop wastes: 1) Legumes 2) Potatoes 3) Sugar beets 4) Vegetables 5) sunflower	1 : 11 : 31 : 31 : 33 : 1	350020002000200025 00	15%65%65%65% 20%
Waste recycling industry: 1) Flour and grain 2) Oil mill 3) Sugar beets (molasses) 4) Beef, small cattle, pork	Waste share:25%20%5% 16%	350035002800 2500	15%15%30% 70%

Biogas production prevents methane from being released into the atmosphere. Methane has a greenhouse effect 21 times stronger than CO_2 and has been in the atmosphere for 12 years. Capturing methane is the best short-term way to prevent global warming. Recycled manure and other waste are used as fertilizer in agriculture. This will reduce the use of chemical fertilizers and reduce the stress on groundwater. A biogas plant (station) is the most active purification system. Any other cleaning system consumes energy but does not produce it. A biogas plant converts waste into biogas and biological fertilizers. Biogas production prevents methane from being released into the atmosphere. Achieving this is the best way to prevent global warming. Biogas plants are construction projects consisting of sealed reactors equipped with a set of supply, heating, mixing systems, wastewater, gas-air and electrical equipment. They process organic waste into biogas, heat and electricity, solid organic and liquid mineral fertilizers and carbon dioxide. A biogas plant, as a rule, includes the following main elements (Fig. 4): tanks for collection and homogenization of liquid raw materials; pumping station; loader of solid raw materials; reactor; cogeneration unit.

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The principle of operation of a biogas plant.

Biogas (waste and green mass) is fed from the tank to the reactor using a pumping station or a screw loader of solid raw materials to collect and homogenize liquid raw materials. The reactor contains beneficial bacteria that feed on biomass. To preserve the life of bacteria, the biomass is heated to 35-38 °C and stirred. The resulting biogas is collected in a warehouse (gas tank) .After purification, biogas is fed into a boiler to generate heat energy or directed to the rotation of a steam and gas generator turbine.

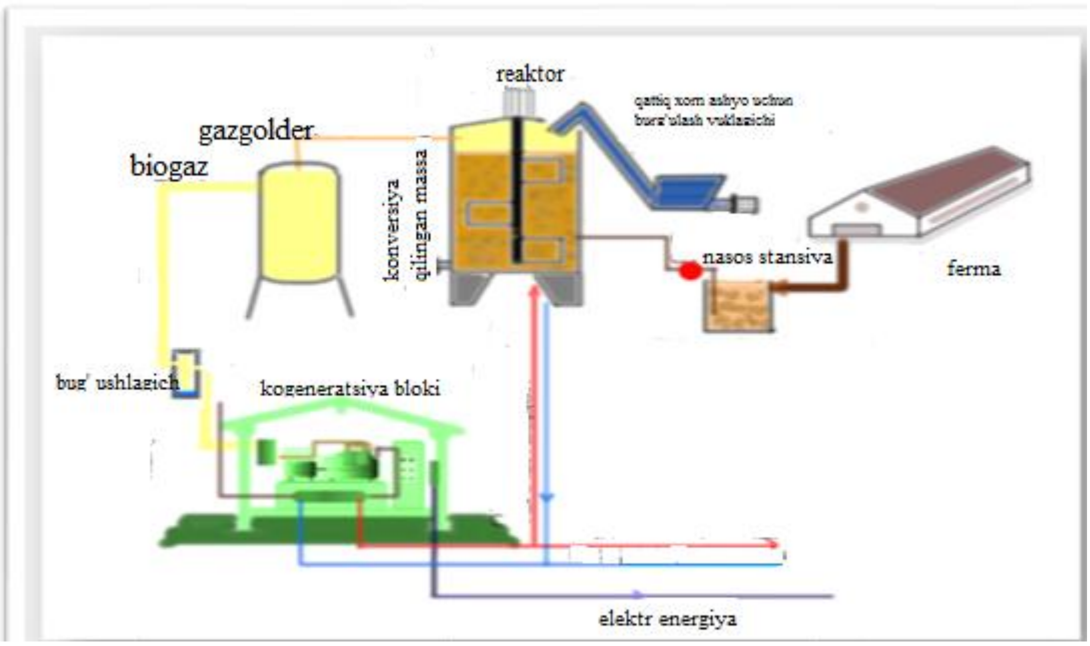

Figure 4. Structure of biogas remote device

A reactor is a heated and insulated device equipped with mixers. The building material for the reactor is usually reinforced concrete or coated steel .The heat losses of a reactor depend on the area of its walls and the ratio of the size and area of the walls in the absolute sense. As the reactor capacity increases, the cost of wall insulation decreases. That is, the specific energy consumption (and therefore the installation efficiency) to maintain the reaction temperature is highly dependent on the absolute dimensions of the reactors. There are currently two ways to generate electricity from biogas. The first uses a gas turbine engine as the propulsion engine for the electric generator, while the second uses a steam turbine unit. Figure 5 shows the structure of a gas turbine power plant (GTP).

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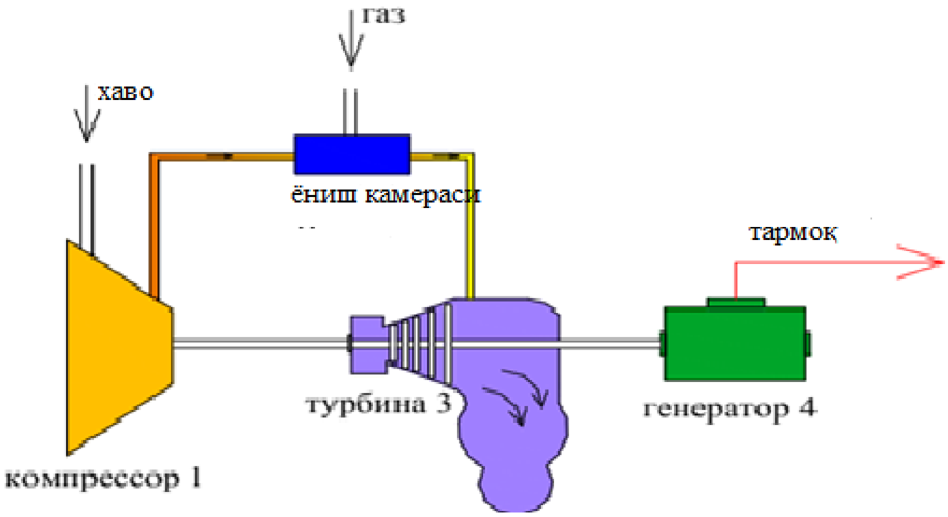

Figure 5. The structure of a gas turbine power plant

The principle of operation of a gas turbine power plant (GTE).

Compressed atmospheric air from the compressor 1 enters the combustion chamber 2, where the main fuel is supplied - gas. The mixture is flammable. When a gas-air mixture burns, a large amount of high-pressure combustion products is formed. The energy in the form of a strong gas jet enters the turbine impeller 3 at high speed and rotates it. In a gas turbine, the energy from the combustion products is converted into mechanical work, some of which is used to compress the air in the compressor. The rest of the work is transferred to the drive unit - an electric generator. 4. The work performed by this unit is beneficial. Electricity is supplied to the grid from the generator output. The main advantages of the gas turbine engine are associated with high operational reliability. On average, the service life of fixed assets without major repairs exceeds 100,000 hours. Gas turbine engines have the following main disadvantages:

1. The cost is much higher than that of reciprocating engines of the same size because the materials used in the turbine must have a high thermal and thermal resistance.

2. Low mechanical and electrical efficiency (gas consumption is 1.5 times higher than that of an electric piston engine with a capacity of 1 kW / h).

3. The need to use high-pressure gas, which requires the use of booster compressors with additional energy consumption and a decrease in the overall efficiency of the system.

The principle of operation of the electrical device of a steam turbine.

Biogas enters the boiler, burns, and radiators containing water are heated above the boiling point (Figure 6). The water evaporates and high-pressure steam is supplied to the turbine blades via the steam line. The water evaporates and high-pressure steam is supplied to the turbine blades via the steam line. The generator is located on the same shaft as the turbine. When the turbine rotates, the generator generates electricity, which is fed into the grid. The steam is cooled in a steam condenser and converted to water. The pump supplies water to the boiler, where the process of recycling water supply is repeated. To improve the operational and technical characteristics of gas turbines and steam turbines, capacitive contactless asynchronous power generators or synchronous generators are driven by permanent magnets should be used [5].

These generators have high reliability, efficiency indicators, their continuous operation resource is several times greater than the resources of controlled electric machines. Moreover, the principles and technical solutions of the voltage stabilizers of these generators are the same. In the considered schemes of devices for the production of electricity from

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biogas, it is advisable to use direct frequency converters as stabilizers of electrical parameters. The principle of operation allows stabilizing the voltage and frequency of the power supply.

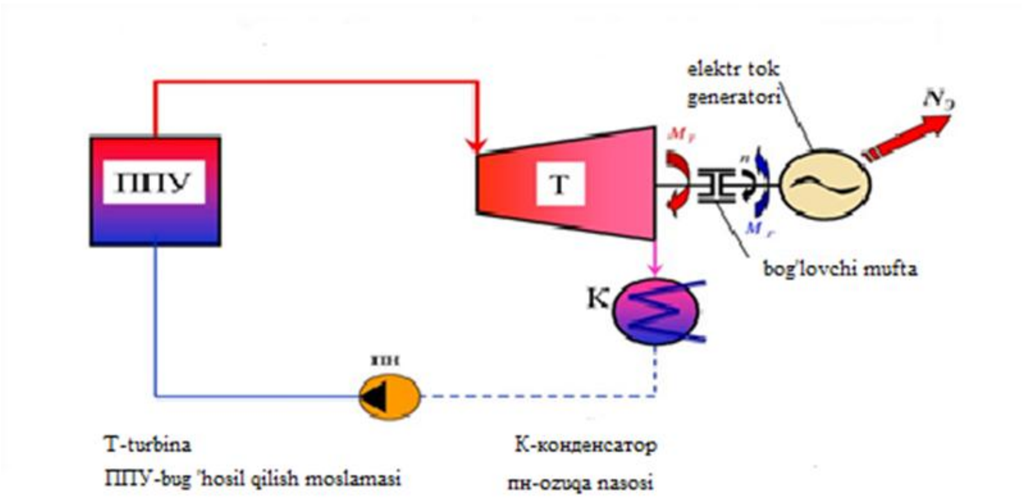

Figure 6. Simplified structure of a steam turbine

III. RESULTS

An important issue in the design of a biogas plant is the optimization of the system according to the main criteria of efficiency (cost, efficiency, reliability, etc.). If we take a closer look at biogas as one of the alternative energy sources at the design stage of a biogas plant, we need to know its main advantages and disadvantages. Biogas benefits:

1. An opportunity, especially for the rural population, that can form a closed production cycle on the farm.
2. Practically inexhaustible self-renewing resource base.
3. Biogas plants are practically on a par with other waste collection plants.
4. Sustainability of electricity production and maximum use of installed capacity.
5. The use of biogas allows you to simultaneously receive several types of energy sources: gas, motor fuel, heat, electricity.

Disadvantages of biogas:

1. Biogas is not environmentally friendly, but this type of fuel does not completely eliminate the greenhouse effect. Although biogas combustion minimizes harmful emissions into the atmosphere, it does not completely eliminate them.
2. The second problem of biogas is the ability to build only in rural areas rich in raw materials for production.
3. Biogas plants, relatively inexpensive for industrial enterprises, but small (individual capacity of several tens of kW) due to high capital costs per unit of capacity, have a relatively high cost.

The cost of 1 kW of electricity installed at a biogas plant ranges from 2 to 5 thousand euros, depending on the capacity of the station. However, a comparison of the level of capital costs per unit of power with other energy sources shows that the energy losses of biogas by this indicator are not clear. For example, the cost of large nuclear power plants is estimated at 5,000 euros per kWh. The cost of 1 kW of large solar photovoltaic installations is 5 thousand euros, wind power plants - 2 thousand euros. Modern thermal power plants are priced at around 2,000 euros per kWh. Currently, biogas can be used depending on the needs of the customer:

1. To provide heat to nearby consumers - farms, greenhouses, agricultural enterprises.

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2. When using a cogeneration plant, the biogas plant can be additionally converted into an energy source.
3. Biogas purification system separates carbon dioxide from methane, which can be used as a vehicle fuel in a gas liquefaction plant.
4. The wastewater treatment system allows the production of clean water in addition to biogas and fertilizers.

Thus, the use of the entire potential of plant biomass in the complex will increase their efficiency, and the payback will be from 3 to 5 years, which is mainly determined by the volume of biomass.

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