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CREATION OF A HYBRID POWER PLANT OPERATING ON THE BASIS OF A GAS TURBINE ENGINE

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This paper considers the issue related to the use of jet gas turbine engines for the generation of thermal and electrical energy, defined as a hybrid energy system powered by biogas. Revealing the main vulnerable points of the use and operation of these systems, it is proposed to use biogas obtained from agricultural, crop and livestock waste as fuel for gas turbine engines.

Analyzing the work of gas turbine engines, it reveals not only the technological advantages of using biogas instead of fuel, but also reducing the cost of heat and electric energy obtained by obtaining a productive land biohumus. This will result, firstly, it is especially emphasized, the usefulness of the resulting ground humus as a waste material, when producing biogas as fuel, for the operation of a hybrid energy system operating on the basis of gas turbine engines. Secondly, during the operation of a hybrid power system, it is possible to simultaneously obtain thermal and electrical energy. Thirdly, the low cost of the heat and electric energy received.

The following are other useful applications of such a power system. The resulting thermal energy is used for heating the greenhouse, and the electrical energy obtained from the operation of the hybrid power system can be used not only for lighting the premises, but can be used for the needs of the greenhouse. It is shown that the proposed hybrid power system consists of two technological structures. The first design is to obtain fuel in the form of biogas for the operation of gas turbine engines, the second design is the connection of the first design with gas turbine engines. A schematic diagram of the general design of the proposed hybrid power system and the principle of its operation is proposed. The difficulties encountered in the design and operation of such hybrid power systems are noted

Keywords: hybrid power system, gas turbine engine, greenhouse, thermal energy, electric energy, humus soil

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1. Introduction

The reduction of reserves of traditional energy sources and the tendency to increase energy efficiency are forcing people to look for more and more sophisticated methods of using traditional and non-traditional energy sources. Recently, hybrid power supply systems have become very popular. They provide for the use of various renewable energy sources. Electrical energy is generated using solar photovoltaic panels, wind turbines or other conversion systems. Thermal energy generation for heating systems, hot water supply and technological processes is carried out using solar collectors (flat and fractal), geothermal systems, as well as other heat energy converters. In [1, 2] a concept for the creation of hybrid power plants is proposed. The essence of this concept is as follows. The combination of various renewable energy sources is not only the presence of elements such as solar collectors, photovoltaic panels, wind turbines, but also the use of a single control system to ensure the effective collaboration of these elements, which forms the basis of a more stable hybrid energy supply system [1].

In recent years, the pace of development of high technologies has increased significantly. Renewable energy sources (RES) have become the focus of attention of power engineers, physicists, scientists and politicians. In this regard, intensive development of renewable energy technology has begun. To cover the energy needs of geographically remote regions from large cities, a large-scale introduction of affordable alternative energy sources into this sphere is required. Since it is impractical, and sometimes impossible, to carry out various types of power transmission lines to these regions, the optimal way to ensure energy supply to these regions is to use renewable energy for this purpose. Such RES can be the sun, wind and biofuels. But here there are difficulties in using these technologies. These difficulties are related to weather and geographical conditions. If the weather is cloudy, it is inefficient to use solar panels, and if the weather is not windy, then it is not effective to use wind generators, etc. This situation suggests the idea of creating a modular hybrid power system that simultaneously provides electrical and other types of energy regardless of weather conditions.

For this purpose, gas turbine engines (GTE) can be used. At the same time, using biogas obtained from crop or animal husbandry waste instead of fuel for these engines.

The creation of hybrid energy systems based on GTE engines of various capacities for remote regions is in demand. Such an energy system should have a modular design. Each module could generate electrical or thermal energy.

Development of the design and principles of operation of a hybrid power system based on a gas turbine generator powered by biogas.

Trends in the energy system in the world are associated with an increase not only in various types of energy, but also in the share of distributed generation based on various energy sources. Distributed generation systems are a hybrid energy supply system combined from various energy sources that are built directly in proximity to consumers and take into account their individual characteristics as much as possible in terms of power and profile. The growth of the share of distributed generation in power systems not only has positive aspects, but also creates certain technical problems associated with changes in the properties of systems, their ability to work continuously under normal and emergency conditions.

The main distinguishing feature of the proposed hybrid power system is the stochastic nature of the parameters of the primary energy source, therefore, the energy generated from these sources creates new problems for consumers. The task of modern energy systems is the constant balancing of supply and demand, flexible management of the complex and ensuring an optimal level of efficiency. These problems can be solved in the mode of dispatching and automatic control of the energy system. It is necessary to develop mathematical models describing the development of energy systems and energy supply systems.

The advantages of such a hybrid power system of use for farms located in remote regions, where it is difficult, sometimes impossible, to conduct power transmission lines, are revealed.

From this, firstly, it is especially emphasized the usefulness of the resulting ground humus as a waste material, when producing biogas as a fuel, for the operation of a hybrid energy system operating on the basis of a gas turbine engine. Secondly, during the operation of the hybrid power system, it is possible to simultaneously receive thermal and electrical energy. Thirdly, the low cost of the heat and electric energy received. Using the example of a greenhouse farm, the advantages of the proposed hybrid power system operating on the basis of a gas turbine engine are described. The following are other useful applications of such a power system. Since in a greenhouse, the earthen soil is a determining factor in obtaining a good harvest. And the resulting thermal energy is used to heat the heifer. The electric energy obtained from the operation of the hybrid power system can be used not only for lighting the premises, but can also be used for the needs of the greenhouse. A schematic diagram of such a design and the principle of its operation are proposed. The use of such a hybrid energy system is beneficial for the regions of our country. Firstly, there is an abundance of livestock and agricultural waste, and secondly, there is a lack of electric and thermal energy to serve people in remote regions. Thirdly, in order to ensure the socio-economic conditions of people working in these farms, it is required to provide them with stable energy (electricity, gas, warm water, etc.). For greenhouse farms, the proposed energy system is very acceptable not only providing heat and electricity, but also providing humus soil, which is very, very much in demand today.

Most autonomous energy systems using renewable energy sources that are in operation and offered on the market are technically ready-made products adapted for a strictly defined type of energy equipment. They do not provide the possibility of expanding their functionality and capacity building through new sources of generation. This situation is mainly explained by the fact that the parameters of the received energy generated by a renewable energy source differ significantly in basic technical indicators, such as the type of current, frequency, and the value of the output voltage. The appearance of a large number of combined installations requires systematization of existing devices, which will allow the formation of the most efficient energy supply systems. To find the most optimal technological solutions for a hybrid system, it is necessary to analyze each component separately and systemically as a whole.

The use of reserves of such renewable energy sources for energy production today is in demand in our country. For these purposes, it is relevant to use gas turbine engines running on biogas obtained from agricultural waste, crop production or animal husbandry as an energy system. Such a system can be used not only to obtain thermal and electrical energy, but also to obtain humus soil, which is one of the main factors in increasing yields in greenhouses.

2. Literature review and problem statement

In this study [3] the results show that the combination of solar, wind, gas and battery systems is more reliable, economical and more sustainable than the introduction of systems with a single energy source. But there are still unresolved issues related to supplementing the results of the current study by identifying regions with high biomass and hydropower resources to form numerous HRES configurations for decision-making and to provide an impact on the choice of the best HRES. The reason for this may be to consider using the latest strategies to improve results.

An option to overcome the corresponding difficulties may be in the work of [4]. In this work various hybridization systems are presented, in which solar energy, photovoltaic energy, wind, hydropower, geothermal energy, fossil fuels, biofuels and energy conservation are concentrated. Hybrid strategies and configurations, various hybrid technologies and their levels of synergy are explained.

Also in the work [5] it is about autonomous hybrid power systems based on wind, as well as the fact that a brief description of the available energy storage systems is implemented as an integral part of hybrid power systems. However, since only autonomous hybrid power systems based on wind are considered in this paper, it can be noted that they are unacceptable for operation in the absence of wind.

This approach is used in the work of [6] and a technical and economic analysis of a hybrid photovoltaic system, wind energy and renewable energy in wind-related biomass is presented. The resource potential of solar, wind energy and biomass has been assessed. For a hybrid system, system criteria and commercially acceptable solutions for implementation are provided. In [7] it was investigated that among all autonomous systems, the share of renewable energy sources compared to other configurations is 86.5 %.

In [8] the design characteristics of a gas turbine installation and advanced control methods used in modern industrial power plants are considered. The research was aimed at improving the control characteristics of the GT power plant and optimal operation for a smooth transition of a system with two fuel injectors using hybrid fuel in the energy sector. This article [9] provides an overview of optimization approaches for hybrid systems of distributed generation resources, taking into account both autonomous and networked systems. All this suggests that it is advisable to conduct a study on a hybrid power system. The solution to these problems is the integration of modern technologies using renewable energy sources and the production of biogas from bio-waste as fuel for gas turbine engines.

Having studied the literature, it was found that the possibilities of a hybrid power plant to receive not only thermal and electrical energy, but also productive soil (biohumus) from bio-waste were not considered. Obtaining such soil from bio-waste makes it possible to use it effectively in various farms, especially in greenhouses in remote areas. In particular, it is possible to increase the productivity of year-round agricultural production. It is in this study that the hybridization of the operation of jet gas turbine engines for the production of thermal, electrical energy and the production of productive soil is considered, when using instead of natural gas, biogas obtained from various agricultural and livestock waste. As part of the research described in this article, methods of calculating the practical implementation of the proposed device are proposed, using the example of a greenhouse economy.

In recent years, the pace of development of high technologies has increased significantly. Renewable energy sources (RES) have become the focus of attention of power engineers, physicists, scientists and politicians. In this regard, intensive development of renewable energy technology has begun. To cover the energy needs of geographically remote regions from large cities, a large-scale introduction of affordable alternative energy sources into this sphere is required. Since it is impractical, and sometimes impossible, to carry out various types of power transmission lines to these regions, the optimal way to ensure energy supply to these regions is to use renewable energy for this purpose. Such RES can be the sun, wind and biofuels. But here there are difficulties in using these technologies. These difficulties are related to weather and geographical conditions. If the weather is cloudy, it is inefficient to use solar panels, and if the weather is not windy, then it is not effective to use wind generators, etc. This situation suggests the idea of creating a modular hybrid power system that simultaneously provides electrical and other types of energy regardless of weather conditions. One of such power systems is the use of a gas turbine engine as an energy system powered by biogas obtained from agricultural, livestock and crop waste, which in our country has large reserves.

One of the "forgotten" types of raw materials is biogas, which was used in ancient China and has been "discovered" again in our time. Biogas is a gaseous product obtained as a result of anaerobic, occurring without air access, fermentation of organic substances of various origins. Its main components are methane (CH_4) – 55–70 % and carbon dioxide (CO_2) – 28–43 %, as well as other gases in very small quantities, such as hydrogen sulfide (H_2S).

Biomass energy is the utilization of agricultural, livestock and crop production waste for energy purposes with the production of biogas and organically pure fertilizers. In Kazakhstan's agriculture, the annual output of organic waste is about 40 million tons. Processing of these wastes using biogas technologies will produce about 18 billion cubic meters of biogas, which is equivalent to 14–15 million tons of conventional fuel. Even partial utilization of these resources could reduce the demand for centralized supplies of long–haul fuel to villages and remote consumers, as well as significantly reduce electricity costs for heating purposes.

A stable source of biomass for energy production in Kazakhstan is waste from animal products. The annual output of livestock and poultry waste by dry weight is 22,1 million tons or 8,6 billion m^3 of gas (cattle – 13 million tons, sheep – 6.2 million tons, horses – 1 million tons), plant residues – 17,7 million tons (wheat – 12 million tons, barley – 6 million or 8,9 billion m^3), which is equivalent to 14–15 million tons of conventional fuel, or 12,4 million tons of fuel oil, or more than half of the volume of oil produced.

Despite the reduction in the number of livestock and poultry, the recycling of already accumulated livestock waste is promising. Due to their processing, about 2 million tons of year of biogas can be obtained. Processing of this gas in electric gas generators will allow to receive annually up to 35 billion kW/h of the total energy consumption, with the need for agriculture 19 billion). And at the same time 44 million Gcal of thermal energy.

In addition, if to use biogas to produce electricity, its cost is only 0.025–0.075 dollars per kW/h, while electricity from traditional sources costs 0.1–0.15 dollars per kW/h. Thus, biogas is 2–4 times more economical [10]. Such conclusions were reached by the employees of the NGO "Ecomuseum" of Karaganda, who successfully implemented a pilot project to obtain biogas from organic waste [2].

Summarizing the situation with renewable energy sources (agricultural, livestock and crop waste) in country, there is a problem of efficient use of these sources to obtain not only heat and electricity. In turn, this is due to the design of the construction of obtaining these energies. On the other hand, solving this problem has great commercial significance, but also social significance for people located in these regions.

3. The aim and objectives of the study

The aim of the study is to creation of a hybrid power plant operating on the basis of a gas turbine engine. This will make it possible to generation electric and thermal energy in particular for heating a greenhouse.

To achieve this aim, the following objectives are being solved:

– development of the design and principles of operation of a hybrid power system based on a gas turbine generator (GTE) powered by biogas as fuel obtained from agricultural, livestock and crop waste;

– development of technology for the application of this hybrid power system to solve practical problems (on the example of a greenhouse).

4. Materials and methods

The object of this study is a small-sized hybrid jet engine, it is based on a jet engine and is based on burning fuel in the form of a mixture of biogas and air at the installation of the power system, as well as the transfer of a useful hybrid energy source to the consumer.

Such installations are especially used by consumers, such as office business centers, entertainment and shopping centers, baths, swimming pools, warehouses, fast food centers, small and medium-sized businesses, hospitals, laundries, warm rooms, agricultural farms, etc. The stable operation of this device depends on the purity of the biogas. Here there are some technical problems that require additional research.

The main distinguishing feature of the proposed hybrid power system is the stochastic nature of the parameters of the primary energy source, therefore, the energy generated from these sources creates new problems for consumers. The task of modern energy systems is the constant balancing of supply and demand, flexible management of the complex and ensuring an optimal level of efficiency. These problems can be solved in the mode of dispatching and automatic control of the energy system.

Most autonomous energy systems using renewable energy sources that are in operation and offered on the market are technically ready-made products adapted for a strictly defined type of energy equipment. They do not provide the possibility of expanding their functionality and capacity building through new sources of generation. This situation is mainly explained by the fact that the parameters of the received energy generated by a renewable energy source differ significantly in basic technical indicators, such as the type of current, frequency, and the value of the output voltage. The appearance of a large number of combined installations requires systematization of existing devices, which will allow the formation of the most efficient energy supply systems. To find the optimal technological solutions for a hybrid system, it is necessary to analyze each component separately and systemically as a whole.

The use of such RES reserves for energy generation in country today is in demand. For this purpose, it is relevant to use gas turbine engines powered by biogas obtained from agricultural, crop or animal husbandry waste as an energy system. Since such a system can be easily hybritized in order to obtain not only thermal and electrical energy, but also to obtain humus soil, which are one of the main factors in increasing yields in greenhouses.

5. The results of creation on a hybrid power plant for generating electric and thermal energy, heating a greenhouse and producing biohumus

5. 1. The results of the study of a hybrid power plant generating electric and thermal energy using a gas turbine engine running on biogas

In the combustion chamber, forces are generated that create torque for the shaft located in the combustion chamber (Fig. 1, *a*) and a huge amount of thermal energy is emitted (Fig. 1, *b*). It became possible to use bio-waste to produce heat and electricity at a low cost. Unlike a piston engine, in a GTE, processes occur in a moving gas stream.

Compressed atmospheric air from the compressor enters the combustion chamber, where fuel is also supplied, which, burning, forms a large amount of gaseous combustion products under high pressure. Then, in a gas turbine, the pressure energy of the combustion products is converted into mechanical work due to the rotation of the blades, part of which is spent on compressing the air in the compressor. The rest of the work is transferred to the driven unit. The work consumed by this unit is considered to be the useful work of the engine.

Any fuel that can be dispersed can be used as fuel: gasoline, kerosene, diesel fuel, fuel oil, biogas, natural gas, marine fuel, water gas, alcohol, etc.

Using this property of the gas turbine engine, it is possible to design an efficient hybrid energy system.

If an asynchronous motor (AM) is connected to the GTE shaft, then it is possible to get electricity, if the emitted thermal energy is sent to a boiler with water, then let's get thermal energy as a result, a hybrid power system appears (Fig. 2).

On the basis of this design, it is possible to build a hybrid power system that generates electrical and thermal energy. Fig. 3 shows such a hybrid power system. This system works as follows [6].

The purified atmospheric air enters the air intake (3) from where it enters the compressor inlet (4). In the compressor, the air is compressed and thereby heated to a temperature of 120 °C. After the compressor, air enters a special air duct (5) between the compressor and the combustion chamber. Further, the heated compressed air in front of the combustion chamber (10) is mixed with gaseous fuel (biogas, natural gas), from where a homogeneous gas-air mixture enters the combustion chamber (6) for Gorenje. Leaving the combustion chamber, the heated exhaust gases to a temperature of 250 °C enter the turbine wheel (7), where, expanding, they perform work by rotating it, as well as the gearbox (2) and generator (1) located on the same shaft. After leaving the turbine (7), through the flue (8), exhaust gases with a temperature of 350 °C enter the heat accumulator (9), where they give their heat to the mains water, which is heated to the required temperature there. The exhaust gas temperature at the outlet of the heat accumulator (9) is 70 °C. The rotation speed of the motor shaft is 28000–30000 turn/min, with the help of a gearbox whose gear ratio is 8:1, let's get the rotation speed of the rotor AM 3000–3500 turn/min.

a *b*

Fig. 1. Gas turbine engine in operating mode: *a* – the occurrence of forces that create a moment for the shaft located in the combustion chamber, *b* – the release of a large amount of thermal energy

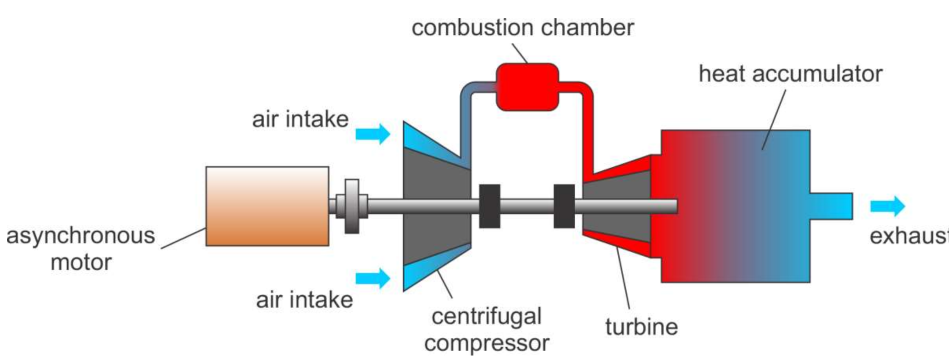

Fig. 2. General scheme of the proposed hybrid power system

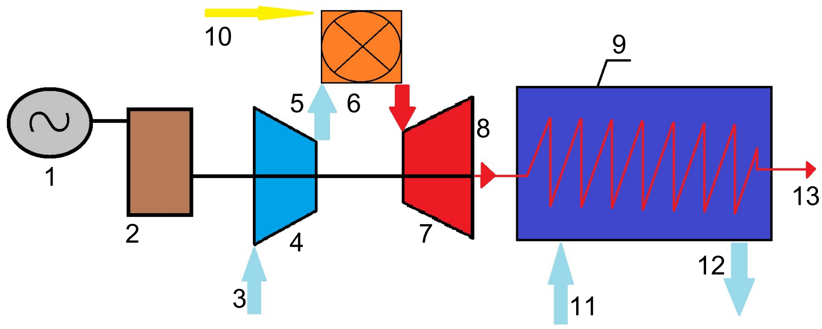

Fig. 3. Hybrid power system based on a gas turbine engine [11]:
1 — generator; 2 — gearbox; 3 — air intake; 4 — compressor; 5 — air duct between compressor and combustion chamber; 6 — combustion chamber; 7 — turbine; 8 — gas passage between turbine and heat accumulator; 9 — heat accumulator; 10 — fuel supply (biogas or natural gas); 11 — cold water inlet; 12 — hot water outlet; 13 — exhaust

As is known, bioenergy is based on the production of biomass, which is used as fuel directly or after appropriate processing. There are three directions of obtaining thermal energy using biomass:

– direct burning of biomass;

– fermentation of biomass;

– the use of energy carriers such as biogas or alcohols extracted during the formation of biomass.

In the first direction, biomass is directly used as fuel by combustion. At the same time, its reserves are restored by growing fast-growing plant species in artificial conditions (aspen, poplar, willow, alder on plantations). Wood fuel has a number of environmental advantages over fossil fuels: the emission of carbon dioxide when burning wood is compensated by the fact that the tree itself absorbs the same amount of carbon dioxide over its lifetime. Disadvantage: large volume, high percentage of moisture.

The second direction is the use of heat, which is released during fermentation of organic waste (manure, sawdust, etc.) and which can be used to heat greenhouses, greenhouses, etc.

The third direction is the extraction of energy carriers from biomass, such as biogas or alcohols. Biogas is obtained from crop or animal husbandry waste. The papers [12, 13] describe the technology of biogas production and propose the concept of a new concept for biogas production from mixed waste [12, 13]. Based on the above, let's design the following biogas production plant (Fig. 4) [8]. This setup works as follows. Let's get biological gas obtained from bio-waste (manure, sawdust, etc.). Bio-waste through the waste receiver is absorbed into the bioreactor to obtain biogas by spraying. The resulting biogas is brought to the desired condition with the help of an agitator, and the gas is filtered through the suction pump and sent to the gas tank. The residue, called organic humus, is transferred to the humus receiver. Humus located in the receiver is an indispensable land product for greenhouses.

On the basis of these two devices, let's build a hybrid power plant that generates electrical and thermal energy using a biogas-powered gas turbine engine (Fig. 5) [9].

Such a station consists of a heat accumulator, a gas turbine engine running on biological gas obtained from biological waste (animal manure, various plant tops, etc.). Fig. 5 shows the general scheme of such a system.

A hybrid thermal power plant consists of a gas turbine engine (21), in which the gas is compressed and heated, and then the energy of the compressed and heated gas is converted into mechanical work on the shaft of a gas turbine, exhaust gases are emitted through a heat accumulator (10).

In the gas turbine engine (21), the processes occur in a moving gas stream. Compressed atmospheric air from the compressor (1) enters the combustion chamber (2), which is also supplied with biogas (11), which, burning, forms a large amount of gaseous combustion products under high pressure. Then, in a gas turbine, the pressure energy of the combustion products is converted into mechanical work due to the rotation of the blades, part of which is spent on compressing air in the compressor (7). The rest of the work is transferred (8) to the driven unit (9). Exhaust gas through the turbines (6) is supplied to the heat accumulator (10). Further, the exhaust gas heating cold water coming from the pipe (3) is ejected through the pipe (5). Hot water in the form of thermal energy is removed from the pipe (4). Biological gas obtained from vermicompost waste from the gas tank (12) is used as fuel. Biogas obtained in the bioreactor (15) passing through the filter (14) is sucked (13) into the gas tank (12). Biological waste enters the bioreactor through suction (17) from the waste receiver (18) located in the receiver (20). The resulting biogas is brought to the desired condition with the help of a stirrer (16), and the gas is sent to the gas tank. The residue, called organic humus, is transferred to the receiver (20). The humus located in the receiver (20) is an indispensable land product for greenhouses.

The generated high-frequency voltage of the generator undergoes a double conversion: from high-frequency alternating to constant, and then to alternating 220 or 380 V with a frequency of 50 or 60 Hz.

To select an asynchronous motor, it is necessary to accurately determine the rotational speed of the rotations per minute of the GTE shaft. $P=\frac{D^2 v^3}{7{,}000}$, kW, where P is the power; D is the diameter of the screw in meters; V is the torque speed in m/s.

Let's consider an approximate calculation of blood pressure on several points.

In practice, the advantages of the proposed power system in the greenhouse economy have been shown. At the same time, another advantage of the proposed hybrid power system was revealed. Waste obtained during the production of biogas in the form of humus soil. Such humus soil is the basis for obtaining a good harvest in a greenhouse. This ensures the all-season greenhouse economy.

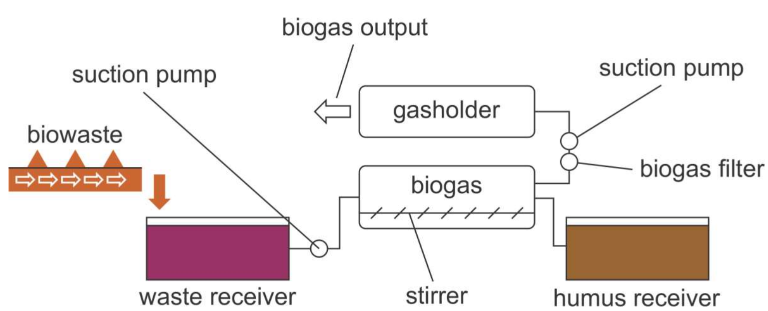

Fig. 4. Biogas production device [14]

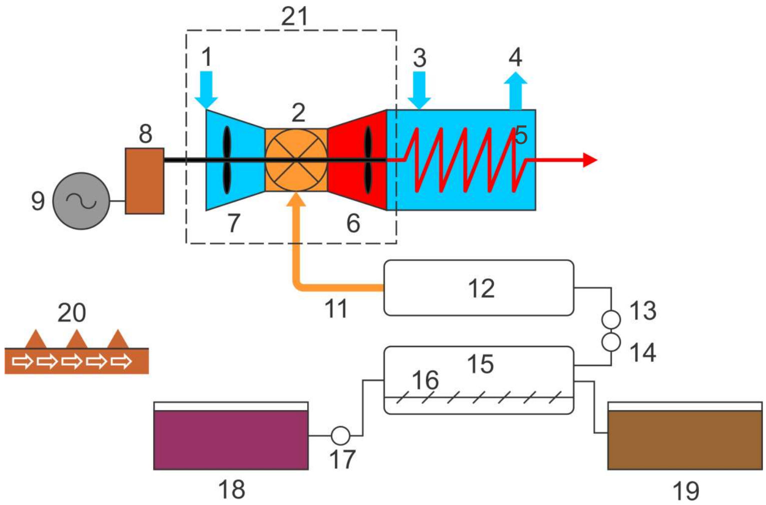

Fig. 5. Hybrid power plant operating with biogas based on gas turbine engine [12]: 1, 7 – compressor; 2 – combustion chamber; 3–5 – pipe; 6 – turbine; 8 – pressure chamber; 9 – driven unit; 10 – heat accumulator; 11 – biogas; 12 – gas tank; 13, 17 – suction; 14 – filter; 15 – bioreactor; 16 – stirrer; 18 – waste receiver; 19, 20 – receiver; 21 – gas turbine engine

In order to select the power of the generator, use the above formula. Initial data for the calculation: D=0.5 m, R=2 Ohm, $P=\frac{D^2}{7}4.5$ W.

Now let's find the generator current from the formula $P=UI$: $I_1=\frac{P}{U}=\frac{120}{220}=0.54$ A. Now let's find the EMF of the wind generator from the formula $E=U+IR$: e_1=220+0.54·2=221 V.

Thus, let's calculate the current and EMF generated by the AM.

Our experiments showed a gas turbine having a size of 30×14×14, with a weight of 10 kg, when using methane gas with a volume of 1 liter, it generated 3.3 kW/h of electricity and 3500 kcal of heat at the same time [13].

Now let's consider the calculation of a biogas plant. To determine the performance of a biogas plant:

1. It is necessary to determine the volume of a one–time loading of a metal tank. If to adopt a continuous loading method, and the volume of the methane tank is calculated for all livestock, then the daily loading volume is defined as the mass of daily excrement, kg:

$$m_{day/ex}=N_a \cdot m_{spec},$$

where N_a – the number of animals; m_{spec} – the specific excrement yield per day.

2. The proportion of dry matter (DM) in the loaded material is determined, kg:

$$m_{dm}=m_{day/ex}\cdot\left(1-\frac{W_{ex}\%}{100}\right),$$

where W_{ex} – the moisture content of the excrement mass, %.

3. The proportion of dry organic matter (DOM) in manure is determined: $m_{dom}=m_{dm}\cdot\left(\frac{P_{dom}\%}{100}\right)$, where P_{dom} % is the proportion of dry organic matter in the dry matter of manure.

4. The output of biogas is determined when the dry organic matter of manure is completely decomposed, m^3: $V_{full}=n_{ex}\cdot m_{dom}$, where n_{ex} the output of biogas from 1 kg of dry organic matter of various source material, m^3/kg.

5. The volume of the biogas obtained is determined at the selected duration of methane fermentation, m^3: $V_b=V_{full}\cdot\frac{n_t}{100}$, where is the percentage of biogas output from the source material for a given duration of the methane process, %.

As the initial data, let's set the following parameters:

– specific excrement yield per day – m_{spec}= =55 kg/day;

– humidity of the excrement mass – W_e=85 %;

– the proportion of dry organic matter in the dry matter of manure – P_{dom} %=80 %;

– biogas output from 1 kg of dry organic matter of various starting materials n_{ex}=0.42 m^3/kg;

– the proportion of biogas output from the source material for a given duration of the methane process – n_t=60 %;

– calorific value of biogas – C_b=21.6 MJ/m^3.

According to the method described above, let's make a calculation that allows to determine the theoretical gross potential of biogas of the projected biogas plant.

Let's determine the volume of a one–time loading of a metal tank: $m_{day/ex}=N_a\cdot m_{spec}$=100·55=5500.

Let's determine the proportion of dry matter in the loaded material:

$$m_{dm}=m_{day/ex}\cdot\left(1-\frac{W_{ex}\%}{100}\right)=$$

$$=5{,}500\left(1-\frac{86}{100}\right)=770 \text{ kg/day.}$$

Let's determine the proportion of dry organic matter in manure:

$$m_{dom}=m_{dm}\cdot\left(\frac{P_{dom}\%}{100}\right)=770\frac{80}{100}=616 \text{ kg/day.}$$

Let's determine the biogas yield at the complete decomposition of dry organic matter according: $V_{full}=n_{ex}\cdot m_{dom}$= =0.42·616=258.7 m^3/day.

Let's determine the volume of the biogas obtained at the selected duration of methane fermentation according:

$$V_b=V_{full}\cdot\frac{n_t}{100}=258.7\cdot\frac{60}{100}=155.2 \text{ m}^3/\text{day.}$$

Let's determine by the formula the potential energy reserves of biogas produced per day:

$$Q_{prod}=V_b\cdot C_b=155.2\cdot 21.6=\frac{3352.32 \text{ MJ}}{\text{day}}.$$

1 t=28.2 m^3=609.5 MJ. The developed hybrid power plant was used for greenhouse heating.

A general scheme of a hybrid electrical system has been drawn up, on the basis of which work has been carried out to obtain electrical and thermal energy. First, a biogas production device was developed. On the basis of this device, a scheme of a hybrid power plant is built that generates electric and thermal energy using a gas turbine engine running on biogas. Secondly, a scheme of a hybrid power plant running on biogas has been drawn up.

5. 2. Results of the study of a hybrid power plant for heating a greenhouse and producing biohumus

The idea of heating a greenhouse developed by a hybrid power system operating on the basis of a gas turbine engine used instead of biogas fuel is quite simple and it works as follows (Fig. 6) [10].

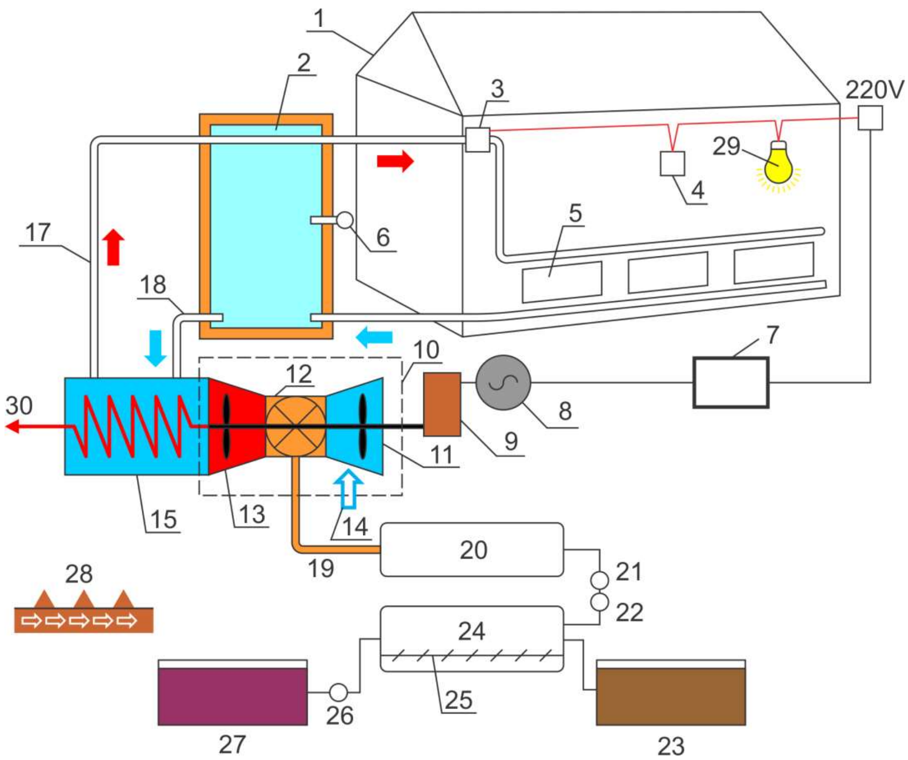

Fig. 6. Greenhouse heating by hybrid power system [13]: 1 – greenhouse ; 2 – thermos tank; 3 – circulating pump; 4 – regulator; 5 – registers; 6 – thermocouple; 7 – distribution network; 8 – driven unit; 9 – pressure chamber; 10 – GTE; 11, 14 – compressor; 12 – combustion chamber; 13 – turbines; 15 – heat accumulator; 16, 17, 18, 30 – pipe; 19 – biogas; 20 – gas tank; 21, 26 – suction; 22 – filter; 23, 28 – receiver; 24 – bioreactor; 25 – stirrer; 26 – suction; 27 – waste receiver; 29 – electrical needs of the greenhouse

The works [15–17] propose a new method for creating an all-season greenhouse economy based on the developed hybrid power plant. As it is known, all-season greenhouse farming depends entirely on humus soil, which is the guarantor of a good harvest, so the proposed concept has a good prospect. To date, the demand for all-season greenhouse farming is in great demand.

In GTE (10), the processes occur in a moving gas stream. Compressed atmospheric air from the compressor (14) enters the combustion chamber (12), where biogas(19) is also supplied, which, burning, forms a large number of gaseous combustion products under high pressure. Then, in a gas turbine, the pressure energy of the combustion products is converted into mechanical work due to the rotation of the blades, part of which is spent on compressing air in the compressor (11). The rest of the work is transferred via (9) to the driven unit (8). The generated electrical energy is transferred through the distribution network (7) to the electrical needs of the greenhouse: (29), (4) and (3).

Exhaust gas is supplied through the turbines (13) to the heat accumulator (15). Then cold water is directed from the pipe (16), exhaust gas heating cold water coming from the pipe (18) is ejected through the pipe (30). Hot water in the form of thermal energy is removed from the pipe (17) and through the thermos tank (2), the temperature of which is regulated by a thermocouple (6), to the circulating pump (3) fed through the regulator (4), is fed to the registers (5) of the greenhouse (1). Biological gas obtained from solid agricultural and livestock waste, from the gas tank (20) is used as fuel in the gas turbine engine. Biogas obtained in the bioreactor (24) passing through the filter (22) is sucked (21) into the gas tank (20). Biological waste enters the bioreactor through suction (26) from the waste receiver (27) located in the receiver (28). The resulting biogas is brought to the desired condition with the help of a stirrer (25), and the gas is sent to the gas tank. The residue, called organic humus, is transferred to the receiver (23). The humus located in the receiver (23) is an indispensable humus – soil or land product for greenhouses. Thus, the proposed utility model provides all-season cultivation of fruit and vegetable products.

Electricity generation. Of course, one of the main advantages of building a biogas plant is the receipt of electricity. The most common method of obtaining electricity from biogas is the use of cogeneration units – gas–piston or gas–turbine engines, the shaft of which is connected by a generator. There may be several options for using the received electricity: electricity supply to local consumers, electricity supply to remote consumers (for example, other enterprises of the same group of companies) by entering into contracts for the transit of electricity with technological networks, the sale of electricity at the "green tariff".

Production of thermal energy. The use of cogeneration plants makes it possible to obtain electric and thermal energy. Thermal energy is transferred in the form of hot water at a temperature of 7500 °C, which is converted by the cogenerator through the heat exchanger and heated in it. The use of boiler-utilisers allows to obtain thermal energy in the form of water or steam with other specified parameters. Thermal energy can be used for heating and hot water supply of administrative and household premises of the enterprise, as well as in technological processes at enterprises. It should be borne in mind that part of the heat and electricity is used for the specific needs of the unit and depends mainly on the climate zone, time of year and raw materials.

The structure and principles of operation of a hybrid power system based on a gas turbine generator powered by biogas as fuel from agricultural, animal husbandry and plant waste were developed, the greenhouse was heated using a hybrid power plant powered by biogas.

The humus released during the production of biogas served as the basis for obtaining a good harvest in a greenhouse with soil.

6. Discussion of the results of the study of a hybrid power plant that generates electric and thermal energy using a gas turbine engine powered by biogas, as well as a hybrid power plant for heating a greenhouse and producing vermicompost

This article proposes the concept of using jet gas turbine engines to create hybrid energy systems. At the same time, it is proposed to use biogas obtained from crop or animal husbandry waste as the basis for the fuel for the gas turbine engine. A schematic diagram of such a design and the principle of its operation are given. This is important because the hybridization of the operation of a biogas-powered gas turbine can be used for remote regions where it is sometimes difficult, it is not possible to draw energy lines.

The study was carried out created on the basis of a jet engine, which is shown in Fig. 3, it is based on the combustion of fuel in the form of a mixture of biogas and air at the installation of the power system and the transfer of a useful hybrid energy source to the consumer. On the basis of this design, a schematic diagram of a hybrid power system generating thermal and electrical energy was created (Fig. 4). A gas turbine engine was used as the basis for the design of a power system generating thermal and electrical energy. At the same time, biogas obtained from the above-mentioned waste was used as fuel for the operation of such an energy system. Thus, the following tasks were solved, giving a practical way out. First, it became possible to use bio-waste to produce heat and electricity at a low cost. Secondly, the possibility of using biogas obtained from bio-waste as fuel for a gas turbine engine has been proved. Third, in practice, the advantages of the proposed power system in the greenhouse economy have been shown. At the same time, it turned out another advantage of the proposed hybrid power system. Waste obtained during the production of biogas in the form of humus soil. Such humus soil is the basis for obtaining a good harvest in a greenhouse. This ensures the all-season greenhouse economy [18–20].

The analysis of the obtained results shows some vulnerable points of the proposed hybrid power system. The first is the problem of cleaning the resulting biogas from CO_2, the second is the choice of an engine to produce stable electrical energy. Automation of the control of the processes of obtaining thermal and electrical energy requires additional research.

This work gives only some recommendations on how to establish the production of hybrid power systems operating on agricultural, livestock and crop waste and reduce the cost of energy generated by obtaining land biohumus.

The generated high-frequency voltage of the generator undergoes a double conversion: from high-frequency AC to DC, and then to AC220 or 380 V with a frequency of 50 or 60 Hz. Experiments have shown a gas turbine having a size of 30×14×14, with a weight of 10 kg, when using methane gas with a volume of 1 liter, it generated 3.3 kW/h of electricity and 3500 kcal of heat simultaneously.

The stable operation of the hybrid jet engine power system installation depends on the purity of the biogas. Here there are some technical problems that require additional research.

This work gives only some recommendations on how to set up the production of hybrid power systems powered by renewable energy sources.

7. Conclusions

1. As a result, schemes of jet gas turbine engines were created that were used to create hybrid energy systems and a general scheme of the proposed hybrid power system. A gas turbine engine is used as the basis for designing a power system that generates thermal and electrical energy.

It has become possible to use bio-waste for the production of heat and electricity at low costs. The possibility of using biogas obtained from bio-waste as fuel for gas turbine engines has been proven.

2. The efficiency of hybrid energy systems was investigated. Biogas obtained from plant or animal waste was used as the basis of fuel for a gas turbine engine.In practice, the advantages of the proposed power system have been demonstrated in a greenhouse. A greenhouse heating scheme was created, developed by a hybrid power system operating on the basis of a gas turbine engine using biogas instead of fuel. And the remaining part, called biohumus, is an indispensable product of humus soil or land for greenhouses. At the same time, another advantage of the proposed hybrid power system was revealed. Waste obtained during the production of biogas in the form of humus soil. Such humus soil is the basis for obtaining a good harvest in a greenhouse. This provides all-season greenhouse savings.This power system capability helps greenhouse managers grow vegetables depending on the humus content in the soil. This is a great advantage of the hybrid power system offered in operation. They received heat and electricity from crop or livestock waste, and also used a developed hybrid power plant to heat the greenhouse and received vermicompost for greenhouses located in remote areas.

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