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DEVELOPMENT OF AN AUTOMATED DIAGNOSTICS AND CONTROL SYSTEM FOR BIOGAS COMBUSTION PROCESSES

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Abstract. *The article shows the ecological and economic efficiency of biogas. Depending on the complexity of the tasks, the mathematical model could describe the research process with varying degrees of accuracy. Thus, numerical simulation should be combined with experimental research to compare and assess the validity of the model. Below is presented, a mathematical model of combustion of biogas. Then, based on the results of pilot studies to validate the mathematical model, a numerical simulation of the combustion of biogas. Process for the combustion of biogas is a complex process of their heterogeneous and homogenous combustion. The model of combustion process of extreme management not good can improve energy performance by maintaining the optimum cop value. Proved by simulation model of extreme management efficiency in changing signal assignments, the maintenance efficiency of the boiler is on a level with the specified accuracy.*

Keywords: biogas, mathematical model, distributed system, optimal control, integration, waste, gasification of fuels

OPRACOWANIE SYSTEMU AUTOMATYCZNEJ DIAGNOSTYKI I STEROWANIA PROCESEM SPALANIA BIOGAZU

Streszczenie. *W artykule pokazano ekologiczną i ekonomiczną efektywność wykorzystania biogazu. W zależności od złożoności rozpatrywanych zadań, model matematyczny może opisywać badany proces z różnym stopniem dokładności. Tak więc modelowanie numeryczne należy połączyć z badaniami eksperymentalnymi żeby porównać i ocenić adekwatność modelu. Niżej będzie przedstawiony model matematyczny procesu spalania biogazu. Zatem, w oparciu o wyniki badań eksperymentalnych mających na celu sprawdzenie poprawności opracowanego modelu matematycznego, przeprowadzona zostanie numeryczna symulacja procesu spalania biogazu. Proces spalania biogazu jest złożonym procesem hetero- i homogenicznego spalania. Uzyskany model ekstremalnej regulacji procesu spalania w kotle pozwala poprawić wydajność energetyczną poprzez utrzymanie optymalnej wydajności. Potwierdzono zdolność roboczą opracowanego modelu symulacyjnego ekstremalnej regulacji przy zmianie sygnału odniesienia, czyli utrzymanie współczynnika sprawności kotła na tym samym poziomie z określoną dokładnością.*

Słowa kluczowe: biogaz, model matematyczny, system rozłożony, optymalne sterowanie, integracja, odpady, gazyfikacja paliwa

Introduction

In the last decade due to decrease of gaseous and liquid fuel resources the problem of energy independence and safety of production processes and life support facilities is becoming increasingly urgent. The growth of the production rate and increasing the percentage of coal enrichment entails an increase for wastes containing organic component in an amount that is economically expedient to use, but it is not suitable for the recycling with the use of existing traditional technologies.

These wastes include sludge of high-coal enrichment plants, as well as small coal, formed by coal mining. Therefore, the technological development of non-fuel use of the organic wastes of coal industry becomes important. Specifically, attention to the study of gasification processes of carbonaceous matters in the superheated steam flow in recent years is increased [1]. The advantage of using a gasifying agent in the form of water steam confirmed by recent foreign researches presented, in particular, in [3–7]. All researches have an aim to realize the technologies of organic raw material conversion using superheated water steam in order to produce high-energy product gas or synthesis gas for chemical production. The creation of industrial recycling technology requires a large amount of experimental researches, which can significantly reduce by combining experimental model studies of conversion by the superheated steam with a numerical process simulation.

1. Methods

A modern technology treatment plant for municipal wasters is connected to substantial large quantities consumption for production electric and thermal energy. At municipality waste-water treatment plants every year spent over 735 million kWh and heat nearly 1 million GCal only. In the conditions of sharp energy crisis the problem reducing energy costs by the use of non-conventional renewable of energy, the use of available on treatment plants themselves and renewed permanently, is still acute and urgent. Direction, which covers all the methods of preparation and use of energy and fuels from organic material (sediments), has been called bioenergy. The development of this trend will lead to significant savings in conventional fuels. Equally important is the environmental aspect, as energy recycling organic waste will significantly reduce pollution. To effectively solve the problem of sludge treatment developed project, which aims to reduce the negative effect of sewage sludge on the environment, the improvement of their transport, dewaring and disposal; Repaying, ecologic and energy-saving technology. The project is provided through the creation of complex sewage sludge treatment facilities, including their anaerobic digestion in the digesters, the use of biogas for power generation in the motor in the motor generators with waste heat recovery for heating and mechanical dewatering precipitation total volume of precipitation using flocculants. The complexity of methods of direct field measurements and their high cost is the reason that these kinds of research are few. A variety of local conditions, the heterogeneity of the objects of study, their variability in time made it difficult to obtain reliable results statically and requires years of research. In this regard, the full-scale experiments are highly isolated, especially domestic practice. Therefore, the basic tool of research remains the use of modern mathematical apparatus and mathematical modeling of processes in time to release. A modeling must be considered on the one hand as an indicator about the expected trends in education of biogas, with another used to be broader and more flexible depending on taskbar. Biogas is a mixture of methane and carbon dioxide produced in the process of anaerobic digestion in biological reactors-digesters. The energy generated by the combustion of biogas, can go from 60 to 90% of the one which has the source material. Of interest is the possibility of collecting biogas produced in the process of anaerobic digestion in biological reactors, and its use as an energy feedstock. Annual methane emission in the world, valuable energy biogas component exceeds 1 billion. cubic meter/year. This potential is now practically unused. A great contribution to the study of the collection and combustion of landfill gas, the processes of decomposition of sewage sludge, gas emissions, the development of biogas collection and utilization technologies, decision related environmental problems have made the work of G. A. Zavarzin’s, V. V. Elistratov’s, Y. M. Likhachev’s, A. B. Livshit’s, E. E. Marinenko’s, A. N. Mirnyi’s, A. N. Nozhevnikov’s, E. S. Pantshava’a, V. V. Raznoschik’s, G. S. Rosenberg’s, E. G. Semin’s, M. P. Fedorova’s, B. Weber’s, R. Cossu’s, O. Tabasarana’s, R. Schtegmanna’s, M. P. Fedorova’s,

V. I. Maslikova's, E. R. Lillyaperg's, A. V. Cheremisina's, S. S. Nurkeev's and others. The results of their research have produced theoretical and practical basis for modeling of the processes of decomposition of sewage sludge, created conditions for evaluation of biogas as an energy feedstock [3].

Practical use of biogas requires determining the real energy capacity, the value of which depends on many factors. Kazakhstan's treatments are inherent to specific features relating to the composition of sewage sludge, storage technology, natural-climatic conditions that require specificity of accumulated knowledge, refinement of mathematical models to predict the emission of biogas and methane content, including using laboratory experiments. Sewage treatment plant is designed for sewage and sediment processing fermentation waste digesters of biogas production and further burning for heat and electric energy. It is linked from treatment complexes and auxiliary structures, interconnected utilities into a single technological scheme [1]. Figure 1 shows the process flow to the treatment of domestic wastewater on separate pressurized filters. Suction chamber is installed to absorb pressure before the facilities. From the camera drains on trays come in a lattice, then pump discharge in sewage camera sand boxes. After sand boxes, drains fall into the distributing bowl dirt collectors. After settlement the drains are trended to the biological refinement.

In this work, the studies of the process of steam gasification of carbonaceous wastes carried out on experimental stand, which schematically shown in Fig. 1. The inner diameter of the reactor was 21 mm. The conversion of the samples was carried out in a dense layer of particles in superheated (up to 1200°C) steam without any access of oxygen at a pressure slightly above atmospheric. Superheated steam produced through the combustion of a stoichiometric mixture of hydrogen and oxygen in a flow of saturated water steam [2]. Costs of saturated steam and a combustible mixture comprised respectively 5 ... 10 l/min (T = 120–130°C) and 2 ... 5 l/min. As the starting material there were used coal wastes (small coal) of the mine with humidity Wa = 1.08%, volatile content Vd = 19.27%, ash content Ad = 9.59% and elemental composition N = 1.51%, C = 77.27% and H = 3.94%. The material was preliminarily carbonized (devolatilization) by heating at 600°C for 30 minutes.

Fractional composition of the particles ranged from 3–4 mm; weight of the sample is about 2.5 g. The concentrations measurements of the reaction products (CO, H_2, CO_2, O_2, CH_4) were carried out on flow gas analyzer Test-1.

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Anaerobic digesters are the only structures with a positive energy balance, which as a result of anaerobic digestion of sediments is formed biogas derived from wastewater treatment. Calorific value and the quantity of biogas depend on its composition, i.e. the content of the basic component-methane and compose 5000–6000 kcal/m^3. From cubic meter of biogas can get up to 2 kWh of electricity and up to 6 kWh of thermal energy in heating-supply boiler. Water after passing of biological refinement enters the receiving tank, equipped with immersible pumps. Pumps are adjusted depending on the accounting flow of wastewater treatment plants. From discharge tank water using pumps is sent into sewage chamber 3, where bottom up vessel served on. Purified water is collected in a pocket, where it is mixed with sodium hypochlorite and served through the second stage filters 5. The second stage filters loaded sorbent and the water are evaluated from top to bottom. Filters are equipped with centrifugal pumps 7. Washing of filters is carried out purified water from the reservoirs clean rinsing 8. Sodium hypochlorite is produced in Chlorination 6.

Because of experimental researches there have obtained dependences of the formation process of the main products of steam gasification according to the process time at a constant steam consumption, its temperature of the feedstock. The sample weight reduction during the conversion experiment was 12% at a temperature of 735°C and up to 58% at 1000°C.

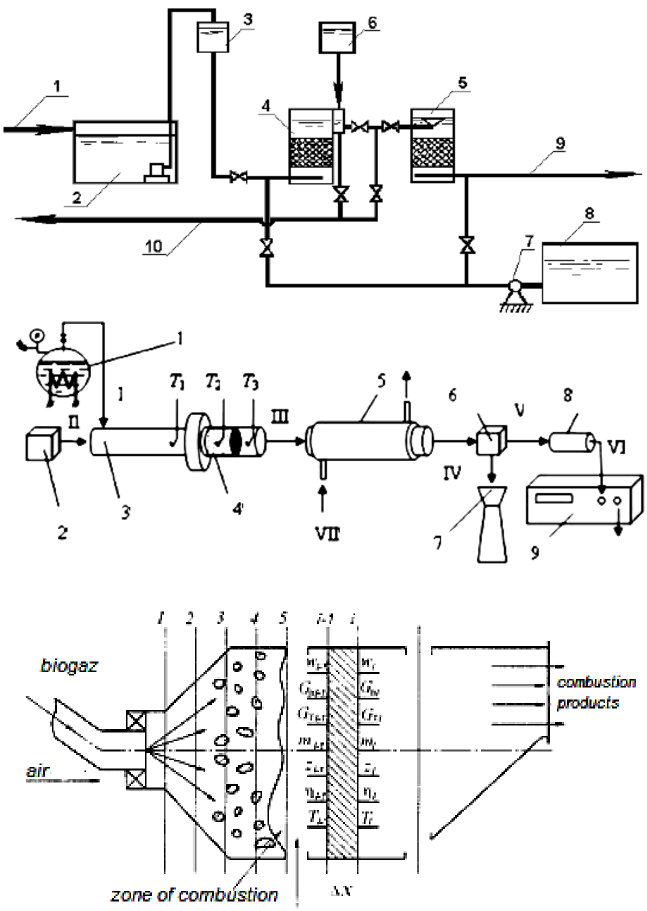


Fig. 1. Diagram of the experimental stand: I – input of low–temperature steam; II – input of high–temperature steam; III – output of steam–gas mixture; IV – condensate output; V – wet gas output; VI – dry gas output; VII – cooling water 1 – steam generator; 2 – generator of combustible mixture; 3 – working area mixing zone; 4 – the reaction zone of the working area; 5 – a condenser; 6 – separation capacity; 7 – capacity of the condensate; 8 – container for gas drying; 9 – gas analyzer; T1, T2, T3 – respectively temperature measuring before reaction zone and after it

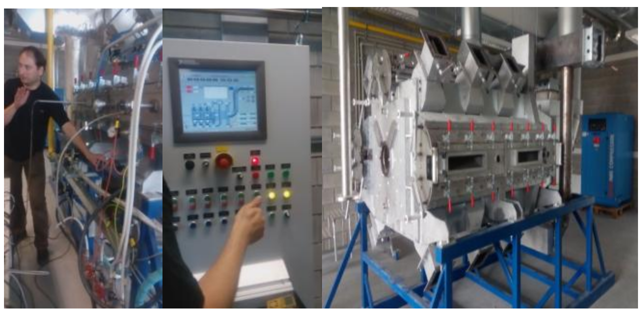


Fig. 2. Exterior installation digester

In order to study the produced biogas as a fuel for the production of electrical energy used by the laboratory stand purchased our university collaborates – the Institute of Electronics and Information Technology, Lublin University of Technology, Poland (Figure 2).

Fig. 3. Cogeneration power plant

In pressure filters the water is supplied from the top down. Entering the sodium hypochlorite produced in the pressure line of the second stage of the filter through a hydraulic elevator. Detainees on lattices dregs manually collected in containers and transported to the city dump. The residue was pumped out of the sand traps on airlifts sand pad to dry. The wet cake from the primary clarifiers pumps installed in a pumping station of raw sludge is removed in the digestion tanks to continue to shop where mechanically dewatered sludge is dewatered on a belt press filters manufactured by "emo". After primary settling effluent contains contamination in the form of fine suspensions, colloidal and dissolved. Further purification involves the use of micro-organisms, which extract impurities from waste in special facilities – aeration tanks. Clarified wastewater in the primary sedimentation tanks in aeration tanks sent by pipeline. The mixture of treated wastewater and activated sludge enters the secondary settling tanks where the sludge settles and the waste water is discharged into the evaporator drive. Figure 2 shows a process diagram of the reception, treatment and discharge of wastewater to the treatment plant SCE "Astana su Arnasy" [1].

As a result of anaerobic treatment organic compounds are degraded to carbon dioxide and methane (biogas). The biogas containing 75–80% methane safely burned in flare heat station (boiler) (Figure 3). It is possible to use biogas to produce steam, hot water or electricity.

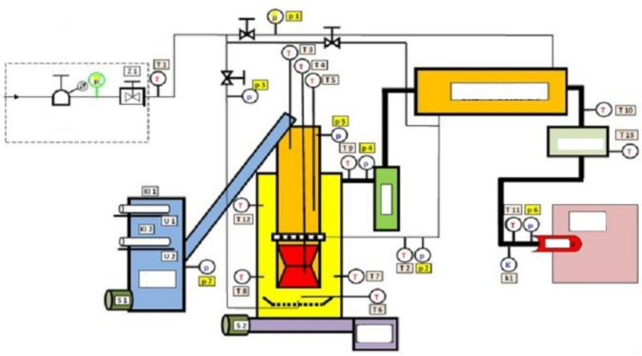


Fig. 4. Scheme of energy production on the block heat station

During the experiments, the value fixed, and examined the relationship of volumes of sewage sludge and biogas produced, their elemental composition, thermo-chemical characteristics of the substrate, the processes of ignition and combustion of biofuels. A separate study of production processes and the combustion of solid fuel: volume, calorific value, ash content, content of harmful substances in exhaust gases, and others.

The following features of the model have identified to address the line extended tasks:

- Assessment of efficiency and accuracy model considered received on the basis of its calculation shall be carried out according to revised data of temperature;
- Data can regarded as orienteer calculated composition for the control of combustion products;
- High sensitivity of the enthalpy of the combustion products to their temperature, can lead to astatic in solving compiled based on a model system of nonlinear equations.

To solve the extended problem taken the points corresponding to $\alpha = 0.4$; 0.7; 1.0. Result calculated flow rate. Solved the problem and direct them to the relevant specified temperature and composition of the products of combustion. In mathematical correct this model, numerical solution obtained by solving system turned bad stable, depending on the initial approximation. To improve the stability of the solution had to found a hard link between the determinable variable not change during the composition of the products of combustion calculations. Relationship between the number of atoms [C] and [H] in the fuel when $\alpha = 1$ (stoichiometric compare components) has been proposed. On the one hand, at $\alpha = 1$ implies

On the other hand, if a stoichiometric amount maximum valencies oxidizing elements equal to the number of valences maximum reducing elements. Therefore, in the case, for example, hydrocarbon and oxygen, this balance can written and the balance thereof by oxygen atoms.

To solve the problem extended equation can used instead as the closing of one of enthalpy balance equations. There is no need in the equations for calculating combustion products of one of the measurements that for kerosene and oxygen is 10 equations and the number of equations in this case reduced from 33 to 23. The production conditions in the extreme regulator the ratio of the volume of races fuel and oxidant corresponding relation can defined as follows:

- The measured flow rates at the maximum temperature found;
- Is based on several measurements temperature dependence of the ratio of fuel costs and oxidant and it the maximum temperature and the corresponding ratio of the volume of expenditure;
- A combination of the first and second method found with ratios in the case of differences.

2. Results

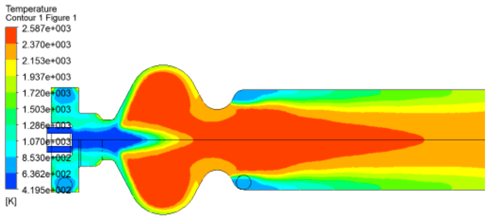
The main feature of the fermentation process – that there are two classes of bacteria and, respectively – the two types of biochemical processes. This feature sets the direction of the search for effective structures of the bioreactor, namely, two-stage with the division of the fermentation process. In this case it is possible to optimize the temperature and composition of biomass for a specific type of bacteria.

The study of multi-level processes implemented within the framework of the technology, is not feasible in terms of the one-sided approach of biological transformations. Formation of the fundamental concepts of the reactions taking place and the establishment of operating in these relationships is feasible only when a comprehensive study of all areas of the process, including chemical transformations in the substrate, the production of biofuels and the production of heat. To implement a comprehensive methodology pilot study carried out modeling of the experimental complex, allowing at the same time to study the behavior of the substrate characteristics of biogas and its burning process at different temperatures (Figure 5). Numerical modeling of aerodynamic processes in the burner of the chemical reactions. Simulated the following processes and effects: turbulence in the reaction medium, the combustion of biogas, the movement of gas particles and radiative exchange. Simulation of the gas phase (volatile, oxygen) was conducted in the Euler approximation and calculation of trajectories of solid particles is in the Lagrangian formulation.

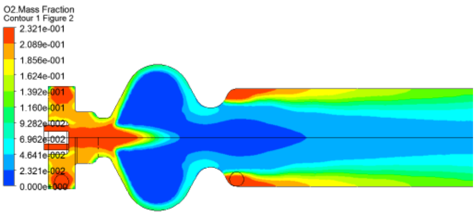
Studies have shown the possibility of organizing biogas combustion process in the burner. Based on the results of the calculation of the burner geometry changed considering the shortcomings of previous models:

- Increase the volume of the combustion field and the output section of the device, which has led to the emergence of the field of return flows and steady combustion zone is generally increasing fuel combustion efficiency up to 60%;
- Reallocate oxidant supply before and after the combustion area, which allowed increasing combustion efficiency by 18–22%;
- Organized a tangential entry of air into the mixing chamber, ensure the stability of the biogas from entering the combustion zone and the lack of breakthrough in particle oxidant supply chamber.

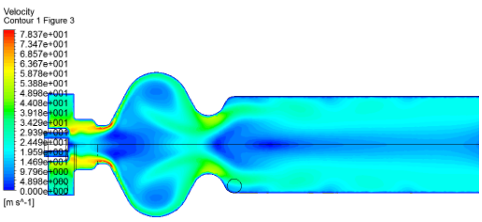
In the end, managed to develop a vortex burner device, the combustion efficiency in which the simulation results is 95%.



a) The temperature distribution in the burner section with two air inlets for α = 1.3



b) Mass distribution of oxygen concentration in the burner section with two air inlets for α = 1.3



c) The velocity field in the burner section for α = 1.3

Fig. 5. The temperature distribution in the burner section

Evaluation of the completeness of combustion device carried to the supply of fuel. For emitted during combustion of biogas analyzed picture of the concentrations of biogas and its dynamics.

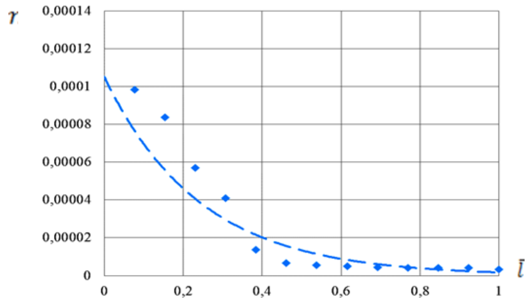


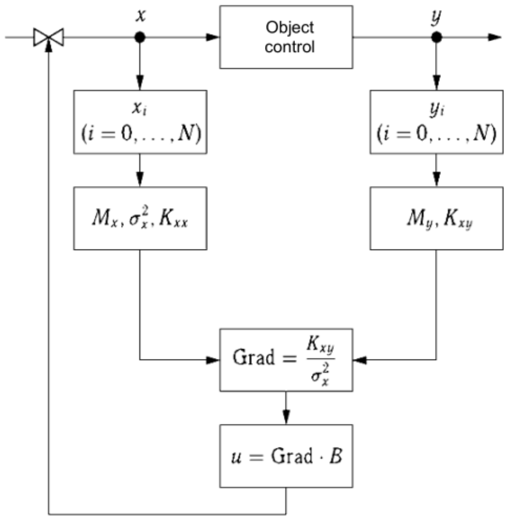
Fig. 6. The analysis of the biogas concentration

During the experiments, the value is fixed, and examined the relationship of volumes of sewage sludge and biogas produced, their elemental composition, thermo-chemical characteristics of the substrate, the processes of ignition and combustion of biofuels. A separate study of production processes and the combustion of solid fuel: volume, calorific value, ash content, content of harmful substances in exhaust gases, and others.

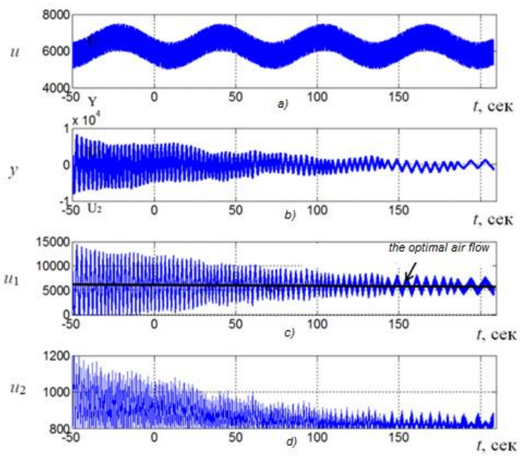
Trial calculations and comparisons of results show a high sensitivity and a large error in the determination of the quantitative composition of the conditional formula fuel and enthalpy. However, the error in determining the composition of combustion products, and not so great in this case does not exceed half of the second significant digit numbers that corresponds to a relative error of about 0.05 (the allowable precision engineering).

A mathematical model based on the type of equations for the fuel gas to determine the quantitative composition of its conditional formula, the enthalpy of the fuel composition of the combustion products using as input values of measured process parameters (fuel cost components corresponding their temperature in the combustion chamber), the well-known element (high-quality) fuel composition ([C], [H], [O]).

The mathematical precision of the model allows to use the data on its basis to assess the sensitivity of the results of calculations based on errors of measuring channels: temperature, combustion products and fuel costs and an oxidant.



a) block diagram of the algorithm of extreme control



b) the simulation results: u – the drift of extreme characteristics; y – a reparative extreme regulator; u_1 – error management; u_2 – the output signal with the extreme object

Fig. 7. Structural CAP program MATLAB and – transitional system for extreme process efficiency regulation

3. Conclusion

Experimental results of the coal waste conversion in the superheated steam flow presented. The method of the experimental data processing developed with the help there are identified kinetics kinetic regularities of the steam conversion. There obtained estimates of the convective heat transfer coefficient of the granular material layer with the steam.

The simulation results of the automatic control unit operation confirmed the efficiency of the developed model. The resulting model of extreme regulation of the combustion process in the furnace can improve the energy performance of the work by maintaining optimum efficiency values. Proved developed a simulation of extreme performance regulation model when changing the reference signal, ie, the maintenance of the boiler efficiency at the same level with a given accuracy.

Modern technology for municipal wastewater treatment is associated with the consumption of significant amounts of electricity and heat. Under conditions of acute energy crisis, the problem of reducing these energy costs with alternative energy sources available on the treatment facilities themselves and constantly renewing is acutely relevant.

This article has viewed as an object of control installation for co-incineration of biogas and natural gas. Mathematic proposed model and method that allows the combustion process of the fuel its composition and ensure optimal parameters of the combustion process. The mathematical model of the process of adsorption of biogas and natural gas.

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