The biogas production effectiveness increase

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Abstract. In the article a classification of biogas units is developed, features of their functioning are disclosed, the card biogas units' processes is developed on the basis of the system and the process approach As a result the conducted researches it is proposed the optimal biogas unit scheme for effective functioning under the conditions of northern Kazakhstan. The essence of the research is that the bioreactor recycling process is activated by double shaft mixer and a dispersing agent, whereupon there may be several mixers according to the volume of a methane tank; a processed organic material is separated in a screw press into solid and liquid fractions, the solid fraction is highly value-added, and the liquid one is returned to the recycling.

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Introduction

Biogas production is of great economic importance for biofuel, heat, electricity, fertilizer receiving, which allows preventing a methane emission, as well as biogas using as a motor fuel [1-3]. Methane influences the greenhouse effect 23 times as more than CO_2 does and remains in the atmosphere for 12 years, a capture of methane is the best short-term way to prevent global warming. Fertilizers, obtained in a bioreactor reduce the amount of applied chemical fertilizers.

Biogas units can be installed as waste disposal treatment plants in farms, poultry farms, distilleries, sugar mills, meat processing plants and may replace veterinary and sanitary plants, i.e. carrion is utilized into biogas instead of meat and bone scraps production [1-6].

Among industrialized countries, the leading position in the production and use of biogas relative indicators belongs to Denmark; biogas takes up to 18% of its total energy balance. By absolute indexes by the number of medium and large units the leading place is occupied by Germany − 8000 thousand pieces. In Western Europe, just under half of all poultry farms are heated by biogas [1-6]. Potential biogas production in Russia up to 72 billion cubic meters per year, it is 151 200 GWh, and 169 344 GWh of heat [1-6].

The advantages of the biogas technology:

- the use of renewable energy of local vegetal and animal raw materials;
- the ability to use economically unused plants up to now (or their parts);
- the possibility of organic waste recycling for energy production;
- decentralized energy supply without multikilometer communications;
- the reduction of greenhouse gases emitting like methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2) into the atmosphere;
- the amount of CO_2 released, which was taken by plants during their growth (closed cycle of CO_2), methane is not emitted into the atmosphere;
- improving the quality of fertilizers compared with unprocessed manure, reducing an odor intensity and alkalinity when applied to the soil, the faster nutrient digestibility of plants compared to untreated manure;
- during the fermentation process the amount of pathogen microbes and weed germination is reduced;
- saving of fertilizers and pesticides, the fermentation residue is an efficient and environmentally compliant substitute for chemical fertilizers.

In the EU countries, a project of Climate Protection "20-20-20" was approved. The aim of this project is to reduce emissions by 20% by the year 2020 and to provide the share of alternative sources of energy by 20% [7, 8]. The energy contained in one cubic meter of biogas, is equivalent to the energy of 0.6 m^3 of natural gas fuel; 0.74 liters of oil; 0.65 liters of diesel fuel; 0.48 liters of gasoline. In the application of biogas fuel oil, coal, electricity and other energy sources are saved as well. Introduction of biogas units improves the stock raising farms environment, poultry farms and in the surrounding areas, preventing a harmful effluents into joists, lakes, ravines as well as small and large rivers. As a result of this the environment is improved [9].

The technology of biogas receiving and its further usage is a complex process which is influenced by many factors, each of which is impossible to estimate separately. For this reason it is necessary to speak about a total plurality of elements that are in significant relationships and connections with each other, forming certain wholeness, unity i.e. about the system. It is a whole total of elements, interacting with each other. There are essential connections, which determine an integrative quality of the system with a certain necessity. For a formation of a system it is necessary to provide ordered connections, i.e. to create a specific organizational structure which consists of interconnected objects and subjects of management, realizing the objective function of a system. Presence of integrative qualities, proper to the system in general, but are not peculiar to any of its components separately.

Technological process of biogas units based on technical, biological, chemical, and other organizational elements of a system, which are in continuous connection with each other.

The technical features include constructional peculiarities of parts and components of a biogas unit. It must have the necessary parts:

-a container for homogenization;
-a downloader of solid (liquid) materials;
-a reactor;
-mixers;
-a gasometer;
-a system of water and hot water mixing;
-gas pipelines;
-a pumping station;
-a separator;
-control devices;
-instrumentation and control with visualization;
-a security system.

Biomass is fed periodically by means of a pumping station or a downloader reactor [10, 11], which is heated and insulated tank equipped with a mixer. Building materials for industrial tank is often reinforced concrete or a coated steel. In small facilities are sometimes used composite materials. In a reactor there live beneficial bacteria that are fed by biomass, a waste product of which is biogas. To maintain the life of bacteria it is required a supply of organic materials, heating up to the desired temperature and periodic mixing. The resulting biogas is collected in a storage (gas tank), then passes through the cleaning system and is supplied to consumers (boiler or electrcall generator). The reactor operates without air, sealed and fire safe [10, 11].

For the fermentation of certain raw materials in pure form special two-stage technology is required. For example, bird brood and distillery stillage are not processed into biogas in a common reactor. For processing such raw materials needs further hydrolysis reactor. This allows the reactor to control the acidity level and bacteria are not killed by content increasing of acids or alkalis. It is possible to process these substrates by a single stage technology, but within a cofermentation (mixing) with other raw materials, such as manure or silage [10, 11].

The biological elements of biogas system include**:**

- fermented biomass composition (content of protein, fat, carbohydrates, lignin);
- the composition of the microflora (number and groups of microorganisms of corresponded decomposition step);
- the microorganisms living conditions (the content of harmful impurities).

Since biogas is a gas produced by hydrogen or methane fermentation of biomass, the decomposition of methane biomass is influenced by three types of bacteria [10, 11]. In a food chain the following bacteria is fed by waste products of earlier ones. The first kind-hydrolytic bacteria, the second – acid forming, third – methane forming; all these bacteria function in animals' organisms. In the production of biogas not only a class of methanogenic bacteria is involved, but all three types. One of the varieties of biogas is biohydrogen, where the final product of the living process of bacteria is not methane, but hydrogen [5-11]. A list of organic wastes, suitable for the production of biogas include: manure, poultry brood, grain and molasses after-distillery stillage, brewer's grain, beetroot pulp, sewage deposits, fish waste and butchering shop (blood, fat, intestine, paunch content), grass, household waste, dairy waste-salty and sweet whey, waste of biodiesel production and technical glycerin from biodiesel production from rapeseed, waste of juices production, fruit pulp, berry, vegetable, grape pomace, algae, waste of starch and molasses production, pulp and syrup, potato processing waste , production of chips, cleaning cloth, a rotten tubers, coffee pulp [10, 11].

Besides waste, biogas can be produced from specially grown energy crops, for example, corn silage or sylphs, and algae, here gas output can reach up to 300 m^3 of 1 ton.

The output of biogas depends on dry material content and the kind of raw material. From 1 ton of cattle manure 50-65 m^3 of biogas is obtained with a methane content of 60%, 150-500 m^3 of biogas from different plant species with methane content of 70% may be obtained. The maximum amount of biogas is 1300m^3 with a methane content up to 87% may be obtained from fat.

Theoretical (physically possible) and technically realizable gas output is distinguished. In 1950-70s technically possible output of gas was only 20-30% of the theoretical one. Today, the use of enzyme boosters for artificial degradation of raw materials (such as ultrasound or liquid cavitators) and other accessories allows increasing the yield of biogas in the most common unit with 60% to 95%.

In biogas calculations concept of dry matter (DM or English TS) or dry residue (CO) is usied. The water, contained in biomass does not give gas.

Physical elements of the biogas production system, affecting the fermentation process [4-11], include:

-a temperature of fermentation;
-a pressure in the biogas unit;
-a hydraulic regime;
-an environment humidity;
-a surface area of the raw material particles;
-a frequency of a substrate feeding;
-retarding substances;
-stimulating agents.

Methane bacteria show their life activity in the temperature range of 0-70 ºC. If the temperature is higher, they begin to die, except for a few strains that can live at temperatures up to 90 ºC. They can survive subzero temperatures, but stop their life activity, in the literature as the lower boundary, temperature 3-4 ºC is indicated. Bacterial strains, which are responsible for the decomposition of biomass are the most productive at temperatures of 250 °C (psychrophilic), 37 °C (mesophilic) or 55 °C (thermophilic) [1-11].

Surface area of raw material particles is important for biomaterial decomposition time: the less substrate particles, the better. The larger an area of bacteria interaction with the materials of the bioreactor and the more fibrous substrate is, the easier and faster the bacteria degrade the substrate. In addition, it is easier to blend, mix and heat it up without a floating crust or a deposit formation. Reduced raw material has an effect on the amount of produced gas through the duration of fermentation. The shorter a period of fermentation, the more material must be ground.

Chemical elements of biogas units:

-acidity (pH);
-VFA content in a fermented mass;
-the volume and composition of biogas;
-pH level;
-the ratio C: N: P.

Composition and quality of biogas comprises 50−87% of methane, 13−50% of CO_2, minor impurities of H_2 and H_2S. After a purification of biogas from CO_2 biomethane is obtained - full analogue of the natural gas, the only difference is the origin.

Since only methane delivers energy from biogas, it is appropriate to describe the quality of gas, the gas output and its quantity through methane with its normalized indicators. Volume of gases depends on temperature and pressure. High temperatures lead to an expansion of gas and the volume decreaseas well as a calorific capacity level, and vice versa. Also with a humidity increase, a calorific capacity of gas is reduced as well.

Organizational elements of the system include:

- the number and periodicity of loading and unloading of the fermented material;
- the possibility of realization of an obtained product (gas, fertilizers, energy, etc.);
- qualitative composition of a loaded mass.

The animal population of Kazakhstan in 2011 (thousand heads) [12]:

5702.4 - cattle, 18091.9 - sheep and goats, 1204.2 – pigs, 1607.4 – horses, 32870.1 – poultry.

Deaths of cattle per 100 goals:

1.7 − cattle 4.1 − sheep and goats, 9 - pigs [12].

Biogas capacity of various materials is shown in the table 1; comparative analysis and indicators' comparison is in the table 2.

Table 1 – Biogas capacity

Biomaterial, one ton	biogas, $м^3$
1	2
Cattle liquid manure	45.0
Swine liquid manure	60.0
Processed grain of distilled and beer industry	65.0
Cattle manure, mixed with straw	70.0
Beetroot top	75.0
Poultry manure	80.0
Beetroot production waste	88.0
Bio waste	100.0
Sugar production bio waste	115.0
Rye harvest waste	165.0
Swine manure, mixed with cattle manure	180.0
Feed beetroot production waste	200.0
Maize silage	250.0
Grass silage	300.0
Butchery waste	350.0

Preliminary calculations (see above) showed the possibility of receiving of more than 174 billion tenge in peasant farms of Kazakhstan. It is only using manure, available in the animals' farms, excluding the application of the organic material of dead animals, silos and other materials with an output of methane, which is ten times as higher as an output of animal manure.

Table 2 – Biogas characteristics' comparison

Index	Value
1.0 $м^3$ of biogas	5.0 – 7.5 kW/h of total power
1.0 $м^3$ of biogas	1.5 – 3.0 kW/h electrical power
1 cattle unit	6.6 – 35.0 t of liquid manure per year
1 hectare of maize silage	7800 – 9100 m^3 of biogas
1.0 $м^3$ of methane	9.97 kW/h of total power
Specific heat of biogas	5500 – 6500 kcal/m^3

Classification of biogas units [1-11].

The shapes of tanks are:

- egg-shaped;
- cylindrical;

- spherical;
- tapered up; down on both sides;
- trenched-formed;
- cubic;
- elastic.

By design peculiarities, biogas units are divided into one reactor and multiple reactors.

For biogas production different technological solutions are used. They can be divided into four typical groups:

By the number of process steps:

Single-stage-two stage;
- multi-stage.

By temperature regimes:
- psycrophilic (up to ~ 25 °C);
- mesophilic (32 to 42 °C);
- thermophilic (50 to 57 °C).

By a loading of a reactor:
- periodic;
- quasi-continuous;
- continuous.

By the relative amount of dry material:
- wet fermentation;
- dry fermentation.

By applying principle of gas, biogas units can be divided into three groups:
- for the production of electricity and heat (during burning in block in mini-TPP);
- for the production of heat (during a burning in a boiler);
- for the production of gas (methane emission and an injection into a pipeline).

By used raw materials:
- agricultural biogas units that use a green mass, which is not exposed by a primary processing and / or waste products of farm animals;
- cofermentational biogas units that use a mixture of agricultural raw materials and organic waste, involved in a primary processing;
- recycling of biogas units, which use different biological waste as a raw material, fermentation of which does not contradict the sanitary-epidemiological requirements.

The most common variant of a biogas unit is a single-stage, mesophilic, quasi-continuously loaded unit of a wet fermentation for the production of electrical energy and heat.

On the basis of a preliminary conducted analysis, we can conclude that the most important thing for improving the efficiency of biogas units under the conditions of northern Kazakhstan is an improving of the technical parameters of the biogas receiving process as system forming elements of a system. The rest must be considered as restrictive when research is conducted.

Peculiarities of animal welfare have a great influence on the functioning of biogas units in northern Kazakhstan. In obtained organic materials contain a large number of matters, different in physical and mechanical composition: animal manure, straw, foreign objects. Straw is a littered material, rich in fiber and is a poor material for obtaining methane. In bioreactor it is separated from manure, float up to the surface and forms a layer which prevents gas formation. Foreign Objects like brick, metal parts and other results of mismanagement hinder the process and lead to machine damages. All this complicates the process of biogas receiving greatly, it is necessary to pre-separate viscous or fee flowing, depending on the humidity, manure from straw, reduction of straw before entering a bioreactor, and if it necessary-cleaning from impurities. Qualitative grinding process of incoming organic material, especially straw, increases speed of fermentation and reduces processing time.

To provide uniformity and destruction of gas-impermeable cover mixers of different designs are used, and choice and validation of the optimal design-mode parameters is a reserve for increase of amount of produced methane. Dispersion also increases the uniformity, and grinding to dispersed state increases the efficiency of a biogas unit.

To create the required humidity a large amount of water is consumed, which is subsequently removed from resulting fertilizer permanently, this is unacceptable in terms of water economy. Moisture together with bacteria should be returned to the process; for this a device for separation of solid and liquid fractions should be highly productive. Obtained fertilizer should receive a high added value and become a real source of income.

A basic variant for validation of approach of designing biogas units may be international quality management system ISO 9001:2000 [13-15], since there is a convergence of goals - efficiency increase, a measure of which, in our case, may be significancy of a process, resources-saving indexes, and quality of obtained products. For qualitative modeling it is necessary to use a process and system approach of the international system [14]. The desired result is achieved more efficiently when activities and related resources are managed as a process.

The main purpose of the process approach is a continuous improvement, which is based on the development of a new model structure, orientation to the needs of consumers, analysis of data the system functioning, maintaining a long steady-state system as a whole and its components [14].

The concept of continuous improvement includes improving by small steps and breakthroughs, periodic assessment of a compliance with established criteria of excellence for determining areas of potential improvement, continuous improvement of all processes.

The successful functioning, the system should identify and manage numerous linked processes, which use resources are and managed with the aim of transformation of inputs into outputs, often output of one process directly forms the input of the next.

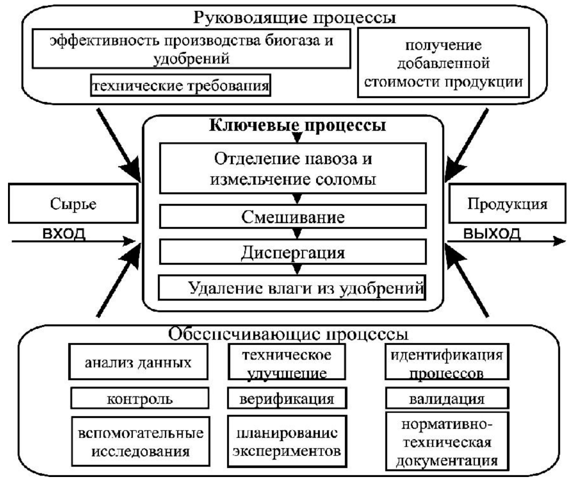

Figure 1 – Flow-process diagram of biogas unit

Руководящие процессы	Guiding processes
Эффективность производства биогаза и удобрений	Efficiency of biogas and fertilizers' production
Технические требования	Technical requirements
Получение добавленной стоимости продукции	Value added products' receiving
Ключевые процессы	Key processes
Отделение навоза и измельчение соломы	Manure separation and straw reduction
Смешивание	Blending
Диспергация	Dispergation
Удаление влаги из удобрений	Fertilizers moisture removing from
Сырьё	Raw material
Вход	Input
Продукция	Product
Выход	Output
Обеспечивающие процессы	Providing processes
Анализ данных	Data analysis
Контроль	Control
Вспомогательные исследования	Supporting research
Техническое улучшение	Technical improvement
Верификация	Verification
Планирование экспериментов	Planning of experiments
Идентификация процессов	Identification of processes
Валидация	Validation
Нормативно-техническая документация	Regulatory technical documantation

Figure 1 shows a map of biogas processes. Controlling processes aimed at process organizing, disclose a purpose of a process and technical requirements for a process. Together with the efficiency of the process goods receives value added, reflecting an economic efficiency. Providing processes are aimed at maintaining, control, correction and prevention of possible deviations from regulatory requirements. In describing the processes there should be considered the components, necessary for its proper functioning [14]:

- define the boundaries of the process;
- to establish the requirements for it;
- identify the inputs and outputs;
- identify the main indicators.

Development of equipment for BGU is associated with the use of a large amount of information, the development of methods of designing of large and complex systems requires the use of the system analysis. In this respect a key analysis is to set optimization problems. Here a typical situation is when a high accuracy is not required in the determination of optimal values of the parameters [15].

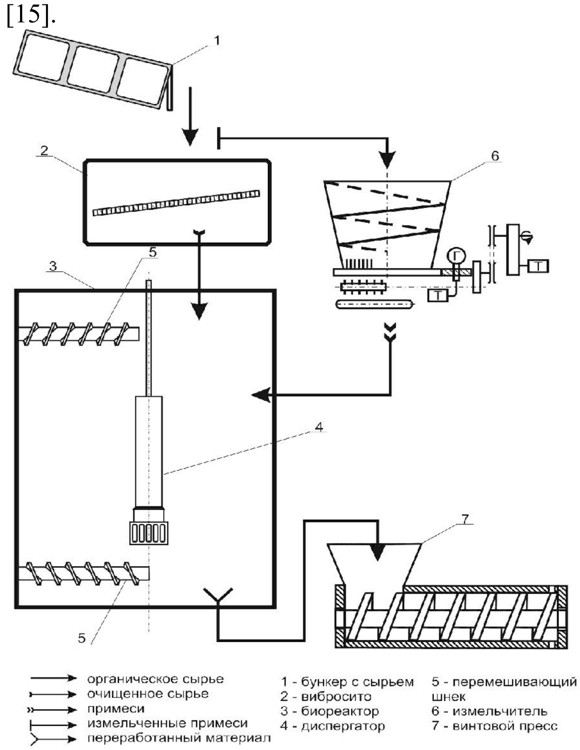

Figure 2 – General process flow diagram of biogas unit functioning

Органическое сырьё	Organic raw material
Очищенное сырьё	Cleaned raw material
Примеси	Impurities
Измельченные примеси	Reduced impurities
Переработанный материал	Processed material
Бункер с сырьём	Bunker with raw material
Вибросито	Vibrating sieve
Биореактор	Bioreactor
Диспергатор	Disperser
Перемешивающий шнек	Mixing screw (auger conveyor)
Измельчитель	Reducing machine
Винтовой пресс	Screw press

Figure 2 shows the general diagram of the offered technological process of a biogas unit functioning, where the disadvantages of the existing equipment are considered. Coming from the animal farm manure enters a vibrating sieve and is separated from impurities, often littered straw, and is sent to a bioreactor, where straw may come after reduction.

In a bioreactor, recycling process is activated by double shaft mixer and a dispersant, wherein there can be several mixers according to the amount methane tank. Recycled organic material is divided into solid and liquid fractions in the screw press; the solid fraction receives a high added value, and the liquid one is returned to the process for reuse.

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