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Development of an industrial-scale bioreactor in the context of a global pandemic

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Abstract. This article provides a comparison of biogas plants for waste processing of various modifications, advantages and disadvantages, as well as a description of a biogas plant of its own development of a horizontal type, taking into account local climatic and economic conditions of farm development, in the context of a pandemic. The article discusses of using of our patented pneumatic motor for mixing biowaste, the bioreactor of own production and comparing the development of biogas station in different countries.

1. Introduction

Efficient using of agricultural waste is a global and important problem in the world. Therefore, development of technology for utilization of liquid cattle manure allows to increase the yield of crops; feed supplements; additional source of energy in the form of biogas become particularly relevant. The using of bioenergy plants makes it possible to obtain mineralized organic fertilizer and biogas [1-12]. Biogas plants based on the production of biogas and biofertilizers by anaerobic digestion of animal waste under the influence of microorganisms helps to prevent global warming is to capture methane. Consumption of this gas reduces the impact of methane.

In farms in Europe and Canada, installations with a capacity of up to 100-200 m^3 of biogas per day are common, which provides the farm with thermal energy in summer by 100%, in winter-by 30-50% [13-24].

2. Materials and methods

Several organizations are engaged in the creation of biogas plants and development of equipment in Russia: CJSC Center "EcoRos", JSC "Stroitekhnika", GNU RESH (Moscow), LLC "Company LMV Wind Power" (Khabarovsk), LLC "Transfin "(Rybinsk), JSC "Stroitekhnika-Tula Plant", etc.[22-23]

"Factor Ltd" company (Moscow) has developed and implemented a prototype biogas plant at the Balakhninskaya poultry farm (Nizhny Novgorod region) (figure 1).

BIOEN-1 is equipped with four digesters with a total capacity of 8.8 m^3, four tanks with "wet" type - 12 m^3, electric power 4 kW (based on commercially available generator AB-4T/400-M2 Viazemsky

electromechanical plant of Smolensk region, documentation of JSC "Agrodizel", Moscow), the heating gas fired unit boilers-23, 2-1 heat capacity of 23 kW, commercially available Zhukovsky machine-building plant (Zhukovsky town of Moscow region), flameless infrared gas burner heat output 5 kW household gas stoves [11-12; 22-23].

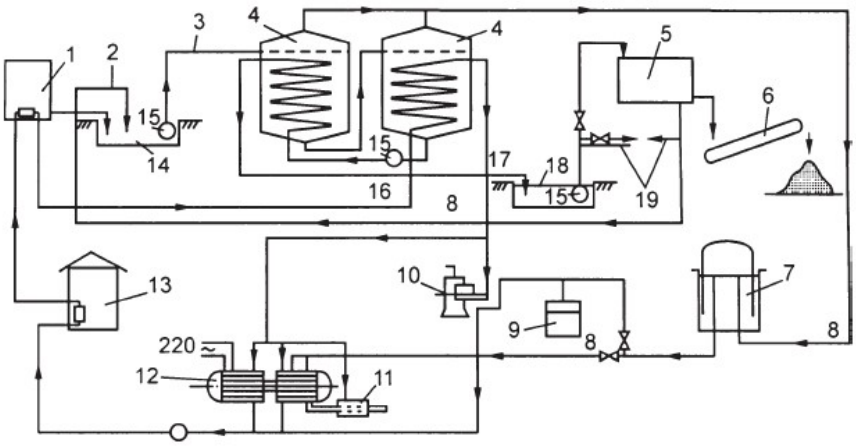

Figure 1. Technological scheme of the autonomous bio-energy block module BIOEN-1: 1-farm.

The biogas industry is also developing in Kazakhstan, although it cannot yet compete with other areas of renewable energy. Nevertheless, the share of biogas energy in 2019 amounted to 18 million kWh or 0.75% of all RES electricity. Three biogas plants (BGS) generated this energy with a total capacity of 2.42 MW, which are monitored by the Ministry of Energy of the Republic of Kazakhstan on a quarterly basis. Since this year, this list includes another BGS-Water Resources-Marketing LLP with an installed capacity of 0.4 MW at the sewage treatment plants of Shymkent. Thus, according to the Ministry of Energy, 2.82 MW of biogas capacity will be monitored in 2020. One of those included in the list – a 1 MW biogas station built from railway tanks – belongs to the Karaganda agro-industrial complex "Volynsky" LLP. The raw material for its operation is pig farm waste; the generated electricity supports the operation of the fish shop of the complex. The biogas plant for 0.35 MW of “Karaman-K” LLP is located in the Kostanay region and operates on the waste of a cattle farm; the generated electricity is directed to its own needs. The development of the project and delivery of the equipment of this station was carried out by LLC "Zorg biogas Ukraine". The same supplier provided similar services to Karaganda LLP "Agrofirma Kurma" for the construction of BGS with a capacity of 1.07 MW [2-3; 10]

Currently, biogas plants with various design and technological features have been developed. There are industrial and artisanal installations. Industrial installations differ from artisanal ones in the presence of mechanization, heating systems, homogenization, and automation. Types of biogas plants are classified according to the methods of loading raw materials, methods of collecting biogas, materials used for their construction, using of additional devices, the horizontal or vertical location of the reactor, underground or ground construction. Two-stage and one-stage biogas complexes are used. Single-stage technology is used for most substrates and this technology can be considered basic. According to the number of stages of the installation process, there are single-stage, two-stage and multi-stage installations.

In continuous operation, the substrate is fed into the bioreactor continuously or at short intervals, while the corresponding volume of the fermented substrate is removed. Installations operating in continuous mode are characterized by stability and high performance compared to other modes.

According to the position of the bioreactors are vertical, horizontal and inclined. The choice of location of the reactor depends on the operating mode and the availability of free territory. In our case, we use a bioreactor of a horizontal type, semi-underground location with continuous operation. This bioreactor allows you to save energy on mixing and keep warm in cold weather conditions [21-22].

In addition, biogas plants are distinguished by the method of heat supply and the method of mixing. The heat required for the process can be supplied directly or indirectly. For our bioreactor, we use an indirect method, since the direct method is performed directly by supplying hot water or steam under pressure to the fermentation mass [3-5; 21-22].

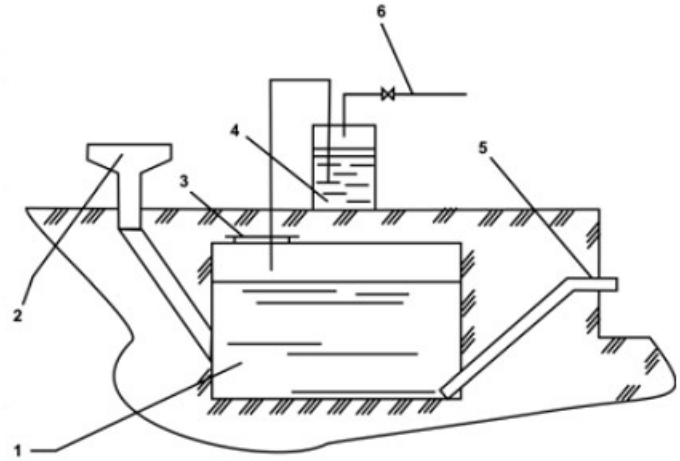

Figure 2. Diagram of the simplest biogas plant with manual loading without mixing and without heating of raw materials in the reactor: 1 - reactor; 2 - loading hopper; 3 - access hatch to the reactor; 4 - water gate; 5 - discharge pipe; 6 - biogas outlet.

The biogas plant (figure 2) is designed for small farms. The reactor volume is from 3 to 10 m^3, designed for processing 50-200 kg of manure per day. The plant contains a minimum of components to ensure the processing of manure and the production of biofertilizers and biogas. And it works in a psychophysics temperature range from 5° C to 20° C. The biogas produced by the plant is immediately sent for use in gas appliances. The processed mass is removed from the reactor through the discharge pipe at the time of loading the next batch of raw materials or due to the pressure of biogas. The discharged fermented mass enters a temporary storage tank, which must be at least the volume of the reactor [9; 11; 21-22].

The construction of this installation (figure 3) also does not require large financial costs. To increase the efficiency of the biogas plant, a device for manual mixing of raw materials was installed. The plant operates in a psychophysics mode, without heating the raw materials in the reactor.

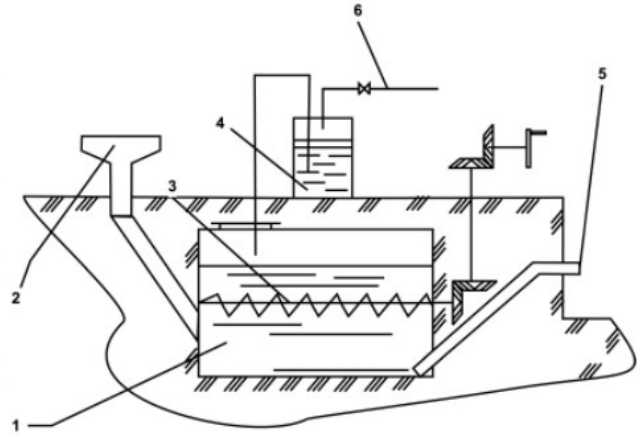

Figure 3. Diagram of a simple biogas plant with manual loading and mixing of raw materials in the reactor: 1 - reactor; 2 - loading hopper; 3 - mixing device; 4 - water gate; 5 - discharge pipe; 6 - biogas discharge.

For a more intensive and stable fermentation process, a reactor heating system is installed (figure 4). The unit can operate in mesophilic and thermophilic modes. The reactor of the biogas plant is heated by a hot water boiler running on the produced biogas. The rest of the biogas is used directly in gas appliances [5; 9-10; 21-22].

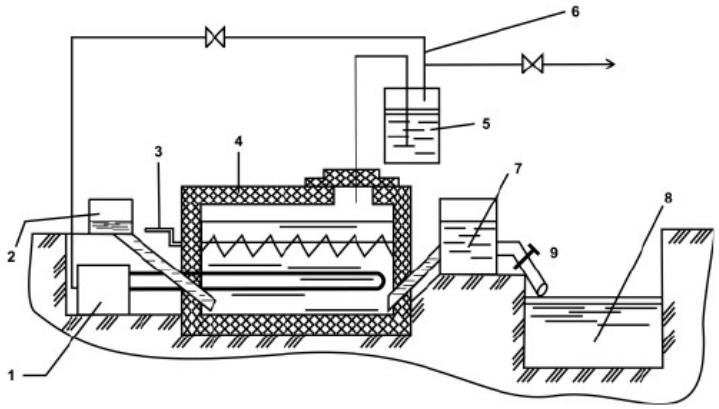

Figure 4. Diagram of a simple biogas plant with manual loading, mixing and heating of raw materials in the reactor: 1 - hot water boiler; 2 - loading hopper; 3 - mixing device; 4 - reactor; 5 - water gate; 6 - biogas outlet; 7 - discharge hopper; 8 - biofertilizer storage tank; 9 - discharge pipe.

3. Results

For the realities of Kazakhstan, taking into account economic and climatic factors, in the context of a global pandemic, we invented a domestic bioreactor. Next, we will describe its main features and compare it with existing models. Our bioreactor is made of a ribbed shape, located horizontally and divided into three sections: loading, working and unloading. The working section consists of one or more modules, each of which is equipped with an agitator with a drive and a heat exchanger. In the upper part of each module, a trolley with a drive is mounted on horizontal guides, to which an additional element in the form of a float device is connected (integrated) by means of vertical rods (figure 5).

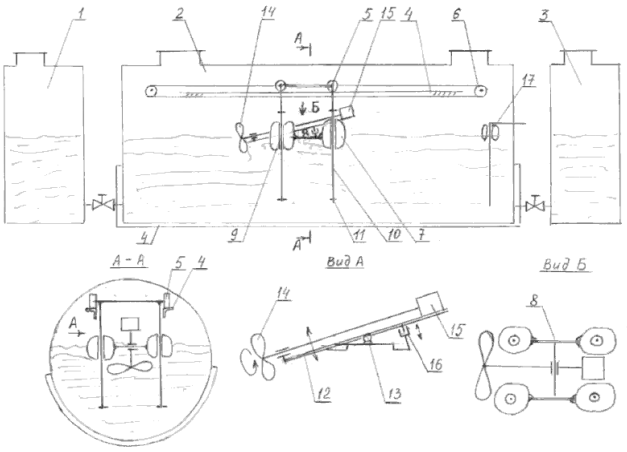

Figure 5. The bioreactor is a horizontal type with float mixing device in the pneumatic engine that runs on compressed air.

Introduction to bioreactor design float device, which is mounted agitator drive with possibility of moving along the bioreactor, and rotation about a horizontal axis in a vertical plane, ensures the achievement of the technical result. [4; 6]

Figure 5 shows a bioreactor with a single module: 1 - boot sector; 2-working sector (module); 3-unloading sector; 4-heat exchange jacket; 5-cart; 6 - wheel drive truck; 7-float; 8-horizontal rods; 9-bushings; 10-vertical rod; 11-limiters; 12-lever; 13-lever axis; 14-agitator; 15-agitator drive; 16-hydro (pneumatic) cylinder; 17-level sensor.

The bioreactor consists of three sections: loading 1, working 2 and unloading 3 (figure 5). The working section can consist of several modules. The module in the lower part has a heat exchange jacket 4.

In each module, a trolley 5 with a drive 6 is mounted in its upper inner part. Inside each module, on the surface of the biomass, there is a float device consisting of floats 7 rigidly fastened together by horizontal rods 8, while each float 7 is movably integrated into a vertical rod 10 by means of bushings 9. Vertical rods 10 are provided with limiters 11 for moving floats 7 along the rods.

On the horizontal rods 8 of the float device, a stirrer 14 with a drive 15 is mounted on a lever 12 with an axis 13. The lever 12 is equipped with a hydro (pneumatic) cylinder 16. To control the level of biomass inside each module there is a level sensor 17, electrically connected to the control system of the hydro (pneumatic) cylinder 16.

Mixing of biomass in each module occurs as follows.

The agitator 14 with a drive 15 mounted on the float device mixes the biomass along the entire length of the module, moving along it by means of a trolley 5, which can be moved, for example, by means of a cable-block drive 6. Vertical rods 10 ensure stable movement of the float device along the module. The limiters 11 do not allow the float device to fall below the critical point at which the agitator could touch the walls of the module.

The agitator 14 with a drive 15, turning with the help of a hydro (pneumatic) cylinder 16 relative to the horizontal axis 13, allows mixing the biomass along the entire height of the module.

The angle of rotation of the lever 12 with the agitator 14 placed on it with the drive 15 relative to the horizontal axis 13 is coordinated depending on the level of biomass in the working section 2 by means of a level sensor 17.

4. Discussion

The quality of mixing of biomass over the entire volume of the bioreactor module, reduce energy consumption for its operation. The bioreactor installation is a horizontal tank, semi-underground type, which allows you to save energy for heating in cold climatic conditions. In addition, a greenhouse can be built over the bioreactor, which allows the production of biogas to use its final products, except for biomethane, such as carbon dioxide and biofertilizers in greenhouse vegetable growing and horticulture. In addition, the use in the bioreactor of the patent invention of a mobile mixing device of the float type, with a pneumatic motor of its own design, gives significant savings in energy consumption during mixing (according to our calculations, up to 60 W at least 40 rpm per 1 m3 of bioreactor volume, for comparison: the best foreign samples have about 100 W per 1 m3 of bioreactor volume at the same speed. Our horizontal bioreactor is made of reinforced concrete construction and provides high-quality thermal insulation and uniform mixing of biomass throughout the bioreactor volume, which is very difficult to implement in the best vertical biogas plants in the world. And also to our biogas plant the peristaltic pump and the chopper of own development is applied patents of RK No. 31872 and №33061 [13-15].

5. Conclusion

The underground location provides for a horizontal bioreactor design due to the obviously lower material costs compared to the low reliability and inefficiency of a low-height vertical design. In addition, according to our preliminary calculations, reinforced concrete construction in Kazakhstan is 1.5-2 times cheaper than steel.

Currently, in many countries of the world, biogas plants with various design features have been created, which operate mainly according to the same scheme. Many of them require the use of thermal energy for heating manure, as well as electricity for mixing and pumping manure. By eliminating the process of heating manure from the outside, the energy intensity of the process and the construction costs of the installation, which is located underground, are reduced.

As a result of the analysis of the market of biogas plants, we have established the following: there are currently no enterprises in Kazakhstan that produce biogas equipment (and even more so

complexes). Foreign equipment is very expensive, which cannot afford to buy even relatively large farms (about 1000 heads of k. r. s.). For example, the cost of a biogas complex in the Kostanay region was 400 million tenge [17], that is, more than 1 million US dollars for a farm where there are about 1000 heads of k. r. s. It is important to note that most suppliers of BSU abroad, including the Russian Federation [18], as well as individual entrepreneurs in the Republic of Kazakhstan [19], widely advertise and sell BSU (and expensive, about 1300 US dollars per 1 m3 of bioreactor), not including such important and necessary equipment for the normal implementation of the technological process as a raw material shredder. Shredders of our development [20] are effective, practical and inexpensive in comparison with foreign analogues (for example, the German shredder of average productivity has a cost of about 13,000 euros.

Against this background, the proposed development of a bioreactor seems to be really effective and takes into account the economic and climatic features of the region as much as possible.

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