Environmental resource saving biogas production

For the poultry breeding farm on the example of “Mikhailovsky broiler”

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***Abstract*—The largest producer of poultry meat in the Far East of Russia, the poultry factory "Mikhailovsky Broiler", in addition to food products, produces waste in large amounts in the form of bird manure. The manure is wasted if it is not recycled but simply stored. By trying to solve the problem of recycling and processing of bird manure, the enterprise has found a way that allows not only to neutralize a huge amount of waste of the fourth class, but also to produce a significant amount of methane gas. When methane is burned, thermal energy is produced that can be used year-round in the technological processes of the enterprise. The second, and no less valuable product of manure processing in the proposed technology is biohumus, which is in demand on local and international markets. In the course of test experiments of the technology in fermenting bird manure, the limitations inherent in the processing of pure poultry manure, other than ruminants' manure, have been clarified. For their elimination the processing technology has been significantly refined by the experts of the research organization, and has been patented. The practical justification for the anaerobic fermentation of the poultry manure was confirmed in the experimental reactor fabricated at the plant in 2011. The proposed manure processing solves the environmental problem, opens up additional sources of resource saving and additional profit for the enterprise. The selling of biohumus to agricultural enterprises in the region makes possible to significantly increase the yield of agricultural crops.**

Keywords—biogas; biohumus; energy saving; agriculture; poultry breeding; manure utilization.

I. Introduction

In the modern world, much attention is paid to the problem of renewable and alternative sources of electrical and thermal energy. Also, projects that solve the problem of improving the ecological situation and at the same time receiving electric and thermal energy are now unique in Russia. The applied scientific research conducted at the Mikhailovsky Broiler enterprise in the period from 2011 to 2014 together with the AgroBioGaz company made it possible to form the scientific basis of litter processing technology in the volume of at least 22 thousand tons per year while simultaneously receiving 10,000 Gcal (11500 MW) of thermal energy annually. A byproduct of the implementation of the technological process for the processing of manure was biohumus, a valuable organic fertilizer free from pathogenic microflora.

II. Actuality

The poultry factory "Mikhailovsky Broiler" is engaged in deep processing of poultry manure, obtained as a result of the enterprise, throughout the entire period of its existence. Litter processing technologies using California Worms, aerobic fermentation technology for manure with natural microflora and forced venting in the thickness of the manure mass, fermentation technology using efficient microorganisms (EM bacteria), and other technologies have been studied and tested. However, it was the technology of anaerobic fermentation of the excretory masses in specialized installations with subsequent production of biogas and biohumus that was promising from the point of view of the products obtained and the possibilities for processing large volumes of raw materials.

The relevance of the proposed project is the availability of its own raw materials base and their needs for the biogas plant, which is at the same time the key to successful implementation of the project.

”Mikhailovsky Broiler” Poultry Factory is the only supplier of basic raw materials for biogas plant operation, as well as the main consumer of generated heat energy with the added advantage of fertilizer as a byproduct of the biogas process that can be sold to local consumers in the agricultural industry.

Competitive advantages of this project includes ”know-how” in the technology of processing chicken manure.

The scientific significance of the project is in developing technology for fermenting bird droppings. The existing methods of fermenting animals’ droppings in order to obtain biogas did not take into account the peculiarities of the organic composition of the bird droppings, and as a result showed their inefficiency during the initial experiments at the poultry farm.

The novelty of the project is in the possibility of practical application of innovative technologies for the creation of an enterprise as a closed ecological bio-production. In this case, the entire food chain is reproduced at one enterprise from the level of microorganisms, enriching the soil with biohumus, cultivating plant products used to produce livestock products, and closing the chain of feedback-processing waste products into products used by the lower levels of the food chain. A similar experience exists in the neighboring People's Republic of China, but so far it is very rare in our country.

DOI: 10.1109/EastConf.2019.8725381

This experience can be effectively used to train the students of the Primorye State Agricultural Academy, who are taking practical classes at the company, and also used during the internship at the Mikhailovskiy Broiler Poultry Factory by the teachers of the Primorye State Agricultural Academy. Established practical business relations with this educational institution will make it possible to apply this knowledge in the educational process. Currently, negotiations are under way with the Primorye State Agricultural Academy on the organization of a branch of zootechnical and veterinary departments at the Mikhailovskiy Broiler Poultry Factory.

III. Formulation of a problem

Mikhailovsky Broiler Poultry Factory is the largest producer of poultry meat in Primorye State and annually produces about 30 - 40 thousand tons of poultry meat. At the same time, as a result of the production process, natural waste products are produced every year in the form of a poultry litter in the amount of 140 thousand tons. Utilization of such volumes of manure is carried out by warehousing, and manure naturally composting for long periods of time, which causes inconvenience to the population of nearby territories and carries an environmental threat. The factory consumes heat energy for keeping the poultry all year round, since even in the summer it is necessary to heat one day old chickens coming for cultivation in the production halls.

To solve the problem of litter disposal and generation of additional heat energy using alternative renewable sources, it was decided to conduct scientific research to develop the technology for processing chicken manure in order to produce biogas as a source of thermal energy [3, 7, 14, 15].

Under the project, 120 tons of chicken manure per day are expected to be processed, and heat energy of 10,000 Gcal (11,500 MW) to be produced annually, as well as production of valuable biohumus in the amount of 36,000 tons per year. The project implementation period (the period from the beginning of the development of design and estimate documentation to the full return of investments by creditors and investors) is 5 years.

IV. Theoretical base

The problems of improvement the efficiency of the biogas processing and its implementation in agriculture were studied and researched by E. S. Pantskhava, A. V. Vinogradova, V. S. Vokhmin, Y. V. Karaeva, V. V. Kovalev [3, 9, 10, 21, 22]. The technological solution for reprocessing pure biomass of chicken manure in a biogas reactor is a complex task, which until now has not been routinely solved by European manufacturers of such installations [1, 8, 16, 18].

The difficulty is that when processing chicken manure (and the litter of other birds) inside the reactor, the concentration of ammonium ions (NH4) and acidity (pH) increases, and the reaction goes out partially or completely.

The usual ways to solve this problem are mixing of additional raw materials rich in carbon (for example, silage grasses), or adding reagents that bind ammonium. In the first case, the complexity lies in the availability of other types of raw materials, and in the second case, the output slurry will be difficult to classify as biofertilizer and get it used for organic farming, since in the manufacture of sludge inorganic reagents are used.

For anaerobic fermentation in a biogas plant reactor, the optimal ratio of carbon and nitrogen (C: N) in the raw feed mixture should be 15: 1. For chicken manure this ratio is 8: 1. The secret lies in the peculiarities of digestion of the bird. Unlike ruminant animals, chickens digest only a small part of the nutrients of the feed, so chicken manure leaves rich undigested proteins, of which ammonium ions are released during hydrolysis. Similar characteristics , although to a lesser degree, are possessed by digestive tracts of pigs and even humans [5], [20].

Only cow dung is ideal for the reaction of anaerobic fermentation, but because of the low nutrient content, the output of biogas from cattle manure is low.

The Mikhailovsky Broiler Poultry Factory together with the AgroBioGaz company developed the technological process of stable anaerobic processing of chicken manure and its approbation was carried out.

The process of anaerobic fermentation with the separation of biogas is conventionally divided into four phases according to the type of processes occurring [19]. Those phase are hydrolysis, acidogenesis, acetogenesis and methanogenesis. Each phase has its own type of bacteria.

During the hydrolysis phase, bacteria break down fats, proteins and carbohydrates into simpler molecules, such as sugars, amino acids, and the like. Bacteria that work in this phase function more efficiently at the temperatures of the psychrophilic regime. Therefore, there is a two-step anaerobic fermentation technology, when the reaction occurs in two series-connected tanks. In the first container, the first two phases of anaerobic fermentation occur at a temperature of 25C. In the second tank, the third and fourth phases occur at a temperature of 37-38C. This solution allows to optimize and stabilize the process for some types of raw materials.

At the phase of acidogenesis, various organic acids are formed. At the phase of acetogenesis, acetic acid is formed. And in the phase of methanogenesis, biogas is formed.

To ensure the possibility of processing chicken manure the following steps are necessary:

1. Physical separation of the first two phases of anaerobic fermentation, which allows to focus on creating the most favorable conditions for bacteria of phases 3 and 4, and also to use the hydrolysis reactor as the site for the preparation of the optimal nutrient mixture for bacteria of phases 3 and 4.

2. Immobilization of bacteria, which occurs due to a change in the design of the reactor and allows it to achieve high stability and survivability of the entire community of bacteria of the fermenter. This is especially important due to the fact that the bacteria of these phases have a very low fission rate. This process reduces the influence of unfavorable factors on the overall survival of the fermenter's biological environment.

DOI: 10.1109/EastConf.2019.8725381

3. Hydraulic multi-channel and multi-point system for mixing the substrate in the reactor. Modern reactors of the standard European design do not allow the use of the method of immobilization of bacteria, because this is hindered by the applied mechanical systems of mixing. The hydraulic system for mixing the substrate in the reactor allows the fermenter contents to be mixed in a qualitative and even manner with any geometrical configuration of the bacteria immobilization means, and also to direct the movement of the substrate in the reactor along a predetermined path.

4. For anaerobic bacteria, it is very important to properly maintain the reaction temperature and to retain not only the temperature but also the first time derivative of the temperature in narrow rigid frames. The modern European method of heating the substrate by reactor walls or by an external heat exchanger allows maintaining these parameters quite roughly [4, 5]. The optimal method of heating is the "warm floor". This system ensures maximum uniformity of heating the substrate in the reactor, and also does not clutter the internal space in the reactor. A system of hydraulic mixing with the removal of the substrate from the bottom of the reactor eliminates the accumulation of sediment on the bottom, which prevents uniform and effective heating of the substrate.

5. The warmed dome allows to significantly reduce the total cost of the installation due to the recycling of secondary heat, "lost" by the reactors, for the purpose of heating all communications, auxiliary units and premises of the installation. Thus, the dome eliminates the influence on the reaction of large fluctuations in external temperature and humidity, allowing to create both designs for a particularly cold climate, and for hot tropical countries. In a hot climate, the dome allows to keep the comfort temperature outside the reactors and in the service rooms by the conditioning method.

The process of anaerobic fermentation differs in temperature conditions. There are three temperature ranges for which local maxima of the intensity of the fermentation process are observed. Indirect indicator of this intensity is the volume of biogas produced per time unit. The first temperature regime of anaerobic fermentation is called psychrophilic. Psychrophilic fermentation occurs in the temperature range 15-25C. The second temperature regime is called mesophilic. Mesophilic fermentation occurs in the temperature range 30-40C. The third temperature regime is called thermophilic. Thermophilic fermentation occurs in the temperature range 50-56C.

With each temperature regime, the metabolism of bacteria occurs about twice as fast as in the previous one. Accordingly, biogas is released about twice as fast. But the higher temperature process is less stable and more whimsical than the previous one.

The proposed installation uses all three modes. Hydrolysis reactor and homogenizer - psychrophilic regime; basic fermenter (methantank) - mesophilic regime; the additional agent (additional methantank batch) - thermophilic mode. The main pathogenic microflora is killed in the fermenter (due to unacceptable conditions for their existence), and particularly resistant pathogenic microorganisms perish in the follower due to increased temperature.

To get the most efficient use of the biogas plant in its development, the following unique technical solutions are used:

1. The presence of a hood-cover from the modern material ensures a constant temperature of the whole complex and thus negates the risks of negative climatic effects (sharp changes in temperature and humidity) and increases the energy efficiency of the complex by minimizing energy losses to the atmosphere.

2. It is possible to adapt the biogas plant to the specific features of a particular enterprise. The mobile laboratory investigates the characteristics of the customer's raw materials and launches the model of the biogas plant. After that, optimal raw materials are established, the strict observance of which is strictly stipulated and is a guarantee of the success of the biogas plant. Only after this, a biogas plant is produced and launched in real scale at the place of its manufacturing. Then, when it passes all testing, it is transported to where it will be installed.

3. The walls of the containers, their covers and the walls of the dome are made of panels 1.2 m * 4 m - multilayer plastic. The planned service life of the panels is 50 years.

4. Bacteria of acetogens and methanogens are immobilized in the main fermenter.

5. Multi-channel multi-point system of hydraulic mixing, redistribution of substrate are made inside the fermenter.

6. Special construction of the reactor foundation allows to insulate the bottom of the reactor thermally from the underlying surface of the earth.

7. Heating system of the substrate uses the "warm floor" method.

8. An additional warmed dome covers all the reactors and other functional units and communications of the biogas plant.

Loading into receiving capacity is based on the actual receipt of the litter. From the receiving container, as it is filled, the litter enters the homogenizer. The volume of the homogenizer is not less than two-day volume of the incoming litter taking into account the volume of water necessary to bring the substrate moisture up to 90%. The amount of water added depends on the humidity of the manure, the density of the dry matter, and the density of the substrate.

The dry matter of the raw material consists of organic and inorganic substances. The ratio of inorganic and organic substances is characterized by such parameter as ash content. These parameters are determined experimentally during the operation of the laboratory process unit, as well as in laboratory conditions. This work has already been completed in 2011.

From the homogenizer, the diluted substrate enters the hydrolysis in portions equal to 1/12 of the total volume of the hydrolysis chamber. The frequency of receipt is determined by the program and adjusted by the automation based on the data

DOI: 10.1109/EastConf.2019.8725381

of the sensors for pH, NH3, etc. The homogenizer is partially supplied with a depressurized and specially prepared filtrate. The volume of water and substrate is constantly adjusted so that the humidity of the output substrate is 90-92%. The percentage of reactor filling is stable and equal to 80%. The residence time of the substrate in the biogas plant is 12 days.

The proposed biogas plant with a common insulated dome ensures maximum independence of biogas production technology from external climatic conditions [13, 17].

All elements of the biogas plant are located inside the lightweight cloth dome, which, on the one hand, protects from the weather, on the other hand provides a relatively stable temperature inside the dome, which is important for the passage of technological processes. The frame of the dome consists of vertical and inclined columns, as well as a rafter system, evenly resting on all the columns.

The second product of the biogas plant is biohumus. In the process of the biogas plant, not only biogas that is produced. Only organic dry substance is decomposed. Such constituents of the substrate as water and inorganic inclusions (sand, ash, etc.) leave the reactor unchanged. 40-60% of organic substance usually turns into biogas, water and mineral salts. The depth of decomposition rarely exceeds 80%. The ratio of organic dry substance to the total mass of the substrate is usually not more than 10%, so when adding a fresh substrate to the biogas plant, almost as much sludge (permeated substrate) is poured out of it, as the substrate is poured. This sludge (methane effluent, methane brew) is an excellent fertilizer of purely organic origin. During the fermentation of the substrate in the reactor, all the potentially harmful environmental factors present in the feedstock disappear, so the sludge usually has a faint smell of baked bread.

The output slurry of the biogas plant consists of water, inorganic insoluble substances, inorganic soluble salts (with predomination of salts containing nitrogen, phosphorus and potassium), partially decomposed organic compounds, among which are useful substances such as humic acids, fulvic acids, various vitamins, and bacteria used in the process of anaerobic fermentation. All of this when applied to the soil provide nutrition to plants, accelerates their growth, improves their resistance to diseases. Due to its ability to heal the soil, the slurry of a biogas plant is often called biohumus. Especially often this name is used for separated sludge, that is pressed to a humidity of 75%. Such a squeezed sludge itself in appearance reminds a layer of fertile soil. Among other advantages, biohumus is an extremely efficient fertilizer. If we express the norms for the introduction of slurry in amounts of nitrogen, phosphorus and potassium, this norms will also be lower than similar standards for the artificially synthesized minerals. Thus, a byproduct of biogas production - the slurry of a biogas plant or biohumus, is an efficient and economical soil regenerator, a concentrated source of soil microorganisms whose vital activity completely restores poor and depleted soils [6]. By using biohumus soil for several years acquires its original strength and fertility.

V. Practical Significance, Proposals and Results of Experimental Studies

In 2011, the Mikhailovsky Broiler Poultry Factory jointly with the AgroBioGaz Company conducted tests of the technology of fermenting bird droppings in a laboratory based biogas plant.

The reaction of anaerobic fermentation of chicken manure cannot start on its own. For effective start, it is necessary to introduce the appropriate bacterial cultures into the fermenter. In our case, the appropriate cultures of bacteria were introduced by filling the fermenter with raw material of animal origin (manure of ruminant animals), rich in such bacteria.

To accelerate the testing, part of the substrate with working culture of the necessary bacteria was left in the fermentor. The right amount of chicken manure substrate, prepared according to the specified recipe, was fed at the entrance of the laboratory biogas plant in order to fill the working volumes of the hydrolysis reactor and fermenter. The working volume of the hydrolysis reactor is 225 liters, the fermenter is 1000 liters. After soaking in the hydrolysis reactor for 12 hours, the plant was switched on to a progressive batch feed of the substrate. Every day, once a day, a substrate was prepared in the preparatory capacity of 200 liters in order to bring its initial volume in the preparatory capacity to 80-100 liters. Controlled by the biogas plant automation, the pump supplied 5.21 liters of substrate every 2 hours to the hydrolysis reactor. The same amount of hydrolyzed substrate was simultaneously automatically poured from the hydrolysis reactor into a fermenter operating in the mesophilic regime (37,50C), same time maintaining the temperature of 250C in the hydrolysis reactor.

Immediately after the reactors were filled with a mixed substrate, the beginning of biogas separation was recorded without a reactor exit into the psychophilic regime (substrate temperature was 18.3C degrees). The biogas composition consisted almost entirely of CO2.

Two days after the full displacement of manure and the start of methane production in the biogas, the daily supply of the substrate was 62.5 liters, which corresponded to the average hydraulic residence time of the substrate in the hydrolysis reactor of 3.6 days, calculated from the total amount of the substrate, and the average hydraulic residence time of the substrate in the fermenter is 12 days. A day later, the dose of the substrate was reduced to 53.57 liters, taking into account the duration of the hydraulic residence of the substrate in the fermenter for 14 days. This mode was kept for 2 days. Then, the daily portion of raw materials was reduced to 46.88 liters, which corresponds to 16 days. This mode was also checked within 24 hours. And then the daily portion of the substrate was reduced to 41.67 liters, which corresponds to 18 days. Thus, the range of possible optimal values of the duration of the cycle of anaerobic fermentation of chicken manure from the poultry of the cellular contents of the Mikhailovsky Broiler Farm was tested.

Anaerobic fermentation of chicken manure in a laboratory installation yielded the following results, “Table 1”:

DOI: 10.1109/EastConf.2019.8725381

TABLE I. MESOPHILIC REGIME

Daily dose of substrate, l	The residence time in the hydrolysis reactor, days	Time spent in the fermenter, days	Daily dose of organic dry matter, kg	Daily output of biogas, m3	CH4 in biogas,%	Specific biogas yield, m3 / kg
62.50	3.6	12	5.89	0.78	55	0.13
53.57	4.2	14	5.05	0.89	59	0.18
46.88	4.8	16	4.42	0.98	61	0.22
41.67	5.4	18	3.93	1.02	61	0.26

The analysis of the biogas composition was carried out for gas samples in optimal modes of anaerobic fermentation, “Table 2”:

TABLE II. ANALYSIS OF THE COMPOSITION OF BIOGAS

Name of gas	Formula	Unit of measure	Mesophilic mode
Methan	CH_4	%	61
Carbon dioxide	CO_2	%	37
Sulfur	H_2S	%	1.4
Ammonia	NH_3	p.p.m.	980
Carbon monoxide	CO	p.p.m.	220
Oxygen	O_2	p.p.m.	140

As a result of the carried out tests at the biogas plant, the limitations of the processing of the poultry's clean dung, which is different than the litter of ruminant animals, were clarified. To eliminate restrictions, processing technology has been significantly modified, refined and patented [11, 12].

Laboratory tests to determine the chemical and bacteriological composition of the obtained sludge and an experimental analysis to determine the activity and suitability of its use as biofertilizers were conducted in 2012 in the laboratories of the Swedish company Eurofins Environment Sweden AB. Research Laboratory of the Agronomical Faculty of the Chuvash State Agricultural Academy in 2017 investigated the chemical composition of solid products for the processing of chicken manure in a biogas plant and confirmed the possibility of using them as a fertilizer for crops under closed and open ground conditions.

The author of this article was directly involved in this project as a representative of the customer company that was an integrated part of the project team, and devoted more than 15 years to the researches of meat and egg poultry production efficiency [23].

Thus, biogas and valuable biogas sludge (biohumus) were obtained using a biogas plant. The consumer of the produced heat energy in full will be the Mikhailovsky Broiler Factory, whose technological processes provide for a year-round need for heat.

Established business connections with local crop producers (producers of grain raw materials, used for poultry feed), allow to fully realize the biohumus obtained. Since there are no analogous production of biohumus with declared quality parameters in the province and the entire Far East of Russia, the enterprise plans to occupy 100% of the bio-humus market.

All the raw materials used for the production of biogas and biohumus are poultry litter and the required amount of technical water is supplied by own production and it will not be purchased from outside. The project implementation will ensure the protection of the environment from contamination by bird droppings, which will improve the environmental situation in the vicinity of Zavodskoi village of Artem urban district.

The company has many year experiences in working with local and regional authorities. As part of the construction of the biogas plant, the interaction with the Department of Natural Resources and Environmental Protection of Primorsky Region and the Department of Agriculture and Food of Primorsky Region is continuously carried out since 2013.

The presentation of the project was held at public hearings at the meetings of the Public Expert Council on Environmental Safety, Preservation of the Environment and the Reproduction of Biological Resources in Primorsky Region (in February and March, 2014) and received its approval and recommendations for its implementation. By the decision of the Public Expert Council, the project was assessed as having a positive environmental perspective, which, if successfully implemented, will become a visiting card of Primorsky Region as an example of the introduction of innovative technologies for generating energy sources based on the utilization of biowaste of the enterprise. It was recommended that the Governor of Primorsky Region considers the project and provides support in its implementation (Protocol No. 10 of March 20, 2014).

Subsequent prospects for the development of the project are represented in the growing of algae chlorella for obtaining green biomass for poultry feed. Algae is planned to be grown using water enriched with carbon dioxide, obtained as a byproduct of the biogas plant in the course of the methane formation reaction and the filtration of the produced gases.

VI. CONCLUSION

The implementation of the concept of using a biogas plant for biogas and biohumus production will allow the company to meet the heat demand for growing broiler chickens by 25% by burning the resulting biogas year-round. The sale of the obtained biofertilizer will compensate for an additional 30% - 40% of the current heat costs.

The proposed technology for processing bird droppings increases the social responsibility of business in improving the environmental situation in the vicinity of Zavodskoi village of Artem urban district, enhances the company's environmental image, partially solves the problem of increasing the company's energy efficiency by reducing the consumption of external energy resources. In general, the introduction of a biogas plant increases the economic efficiency of the factory by reducing the prime cost of the main production of broiler chicken meat. The factory has sufficient human and technological potential for the implementation of this project. The level of qualification of specialists of zootechnical, veterinary and engineering services of the factory, the availability of accredited veterinary and zootechnical

DOI: 10.1109/EastConf.2019.8725381

laboratories allow safe and efficient operation of high-tech biogas equipment.

Mikhailovsky Broiler's own raw materials base and the presence of its own constant heat demand for growing chicken broilers create unique opportunities for the successful implementation of the project.

ACKNOWLEDGMENT

P.V.Y. thanks to A.S. Mandelshtam and AgroBioGaz Company (http://www.agrobiogaz.ru) for the cooperation in research and for assistance in providing technical documentation.

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DOI: 10.1109/EastConf.2019.8725381