Production of Biogas using method of agricultural waste fermentation

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Abstract. During using biogas as fuel for diesel engines, it is necessary to clean it from hydrogen sulfide, water and carbon dioxide, as well as to compressing it to fill cylinders more efficiently. Today the production of biogas in agriculture is the disposal of crop waste and manure from livestock farms. This approach is very actual, at the first stage of its implementation was planned to create the necessary material and technical base to widespread using of non-traditional energy sources, including organic biomass energy (fertilizer, crop waste, etc.). In addition, environmental protection, which also requires intensive and rational processing of animal waste, is very closely connected with the problem of waste disposal. This necessitates the search for processing methods that would ensure the comprehensive utilization of its agricultural, energy, feed and other properties. This article presents the technology for processing the utilization of manure using microbial synthesis. When processing manure in anaerobic conditions, the threshold lowered for its smell, germination of weed seeds, helminths die, and nutrients (nitrogen, phosphorus, and potassium) are completely preserved. The resulting biological gas contains up to 70 % methane, and its calorific value is 24 MJ/M3. The introduction of low-waste, resource-saving technologies with mechanization and automation of production processes plays an important role in the environment protection issues from livestock complexes waste in their further development. At present, there are several directions of processing of agricultural and water waste. At the same time, processing of animal waste with the use of biogas plants gives a significant socio-economic effect, expressed in improving working conditions, increasing the production culture and land use. Moreover, the environment protection rask is being solved.

1. Introduction

The first developments of technology and technical means for cleaning, transporting, storing and using manure appeared with the establishment of mechanized farms for milk production, young stock breeding, pigs, and etc. Further research is aimed to establish environmentally friendly systems for cleaning and utilization of manure for all types of farms and complexes, their location zones. Traditional methods of manure storing and using are not acceptable for dilute manure, the share of which in the organic waste structure from livestock farms and complexes is constantly increasing. This makes it necessary to search processing methods that would ensure the comprehensive utilization of its agrotechnical, energy, feed and other properties. Such direction meets the requirements for the
environment protection, and it requires much less operations, maintenance personnel, a more even
distribution of works volume during the year, that is economically rational to prepare manure for use
immediately.

Biogas produces electricity, hot water for heating and other technological benefits. The biogas
engines can operate on a mixture of 15 ... 20% liquid fuel and 85 ... 80% of methane. Based on
experimental data on biogas production and degree of decomposition of manure, was determined the
most effective doses of the average daily loading of the methane tank.

2. The aim of research
Animal waste is of great value for agricultural production. Their use in regions with dispersed livestock
production is not particularly difficult. In Yakutia, animal husbandry is well developed, in this regard,
there is a problem of manure utilization. This is a big issue because of the high animals concentration in
a limited area and the imbalance between its livestock and agriculturally used areas. In this regard the
goal of the article is to study the technology of processing animal waste by anaerobic treatment for the
thermal energy recovering.

3. Methodology
In methane fermentation process, organic substances are mineralized without air access under the
anaerobic microorganisms, which results in a significant increase of mineral nitrogen proportion due to
the splitting of its associated forms. Along with preventing of organic nutrients losses of processed mass,
unpleasant odors, disinfection and devitalization (weed seeds germination loss) are eliminated.
The study of manure physical and microbiological parameters, as well as their dependencies on the
processing mode and methods, allowed to analyze the known technological schemes and means for
organic waste methane fermentation and obtaining feed additives from it [3 p.2, 7 p. 95].

4. Main part
Scheme of bioenergy plant for 400 animals’ farm:
During fermentation, biogas is released, which enters the gas holder via a gas pipeline or is discharged into the atmosphere through a water seal. From the gas holder, biogas is supplied (as needed) to consumers.

During the testing period, it was processed 215 m$^3$ of manure with a humidity of 91 ... 93 %, and an ash content of 20 %. The total operating time was 4.215 hours, the biogas volume obtained during the tests was 2.360 m$^3$, and its calorific capacitance was 24 ... 26 MJ/m$^3$.

As a result of research, biogas output data, its decomposition degree in the mesophilic mode were obtained (Figure 2). The maximum biogas output was 16.2 m$^3$/day in the first, and 20.3 m$^3$/day in the second modes.

Analysis of manure physical properties after fermentation showed that the absolutely dry ash-free substance decomposition degree was 22 % with a daily 4.5 % loading dose. The manure humidity and its ash content increase after fermentation, which is explained by the partial expenditure of dry matter for the biogas formation.

Based on experimental data on the biogas output and the manure decomposition degree, it was determined the most effective doses of methane tank average daily loading. It is found that the maximum value of this indicator should not exceed 4.5 and 9% in mesophilic and thermophilic modes.

When increasing the loading dose, the biogas output decreases and the process is unstable.

Figure 2 shows the biogas average yield in the thermophilic mode (20.3 m$^3$/t) is higher than in the mesophilic mode (16.2 m$^3$/t). The average daily energy consumption for the process was 59...62 and 1.000...110 kWh. Thus, the energy specific costs for the production of 1 m$^3$ biogas in the thermophilic mode is 1.5 times higher than in the mesophilic mode.

At the same time, it is known that the manure disinfection and the nonsporeforming microflora destruction are achieved in the thermophilic fermentation mode after 72 hours. Therefore, it is advisable that the equipment set for manure anaerobic digestion function in both modes. The calculated data on the organic substances optimal concentration in the fermentable mass (80...90 g/l) correspond to the manure characteristics used in the experiments (humidity 91...93 %). The calculated fermentation...
exposure does not significantly coincide with the test results (in the mesophilic mode – 9 days against 22, in the thermophilic mode – 7 days against 11). The calculated degree of organic matter decomposition is slightly higher (25.9 %) than in tests (22%). The dissolution rate was relatively low due to the high ash content in manure (20 % at a rate of 16 %). The calculated biogas output does not correspond to the experimental data (17.5 m$^3$/t against 16.2 m$^3$/t). This slight overestimation of the biogas output is explained by the higher ash content in the manure. The process efficiency depends on the climate conditions.

The study of manure anaerobic processing has mainly confirmed the process effectiveness. Based on the research results, we developed a technical proposal for the biogas plant design for a 400 heads farm, and determined its technical and economic efficiency. The initial data were taken as the standards for technological design, according to which on a farm with 430 conditional animals, the excrement output per day is 23.7 m$^3$, the sewage total output is 54.8 m$^3$/day with humidity up to 95 %. The technical requirements provide that anaerobic processing is a flow-through process with cyclical execution of operations.

From the methane tank, the biogas passes to a dry gas holder with 600 m$^3$ volume, from where it is used for heating water and other needs of the farm. The fermented mass passes through the airlock to the tank farm and to the heat exchanger for heating the initial mass.

5. Research results and discussions

In accordance with the developed methodology, it is possible to determine the process key parameters and process facility.

Manure collector volume

$$V_{mc} = Q \rho t_i r_h = 110 \text{ m}^3,$$

where $\rho$ – manure density, $\rho = 1$ t/m$^3$; $t_i$ – intake period, $t_i = 2$ days; $r_h = 1.5$.

Capacity of heating tank:

$$V_0 = L \rho t_0 r_h' = 55 \text{ m}^3,$$

where $L$ – daily manure output with 92 % humidity, $L = 55,48 m^3$; $t_0$ – heating period, day; $r_h' = 1$.

Methane tank volume:

$$V_{mt} = 100 L \rho / g = 785 \text{ m}^3,$$

where $g$ – daily dose of the methane tank loading, $g = 4.5 \%$.

Take $V_{mt} = 1000 m^3$ (close to the standard).

Fermentation length:

$$t_f = 100 / q = 22 \text{ day},$$

where $q$ – biogas output, per 1 ton of processed manure, $q = 20 m^3$.

Daily biogas output:

$$G_f = L q = 710 \text{ m}^3.$$

Gas holder volume:

$$V_g = G_f t_{bs} / 24 = 532 \text{ m}^3,$$

where $t_{bs}$ – biogas storage time, h for 1 day.

Take $V_g = 600 m^3$ (close to the standard).

Total thermal energy of obtained biogas

$$Q_t = G_b C_b = 17 000 \text{ MJ},$$

where $C_b$ – biogas calorific capacitance, $C_b = 24 \text{ MJ/m}^3$. 


The heat consumption for heating the initial manure from $t_1 = 8\,^\circ C$ to $t_2 = 35\,^\circ C$ (mesophilic mode temperature)

$$Q_{mm} = L(t_1 - t_2)C_m/\eta = 5\,400\,MJ, \quad (8)$$

where $C_m$ – manure heat capacitance, $C_m = 4.06\,kJ/(kg*^\circ C)$; $\eta$ – heating unit efficiency, $\eta = 0.7$.

The heat consumption for own use

$$Q_{ou} = Q_{mm} + Q_{hlc}/\eta = 9\,990\,MJ, \quad (9)$$

where $Q_{hlc}$ – The heat consumption for heat loss compensation, $Q_{hlc} = 3\,140\,MJ$.

Total amount of biogas for own use,

$$G_{bu} = Q_{ou}/C_b = 415\,m^3.$$

Output of marketable biogas

$$G_{mb} = G_b - G_{bu} = 295\,m^3.$$

Discharge ratio of biogas for own use

$$\eta_b = G_{bu}/G_b = 0.58.$$

The processing equipment capacity is selected based on its operating period, which does not exceed the working shift duration ($t_p < t_{cm}$), if it can be used for the farm thermal needs.

Minimal heat power

$$W_{min} = G_bq_{ng}/t_{ot} = 2\,150\,MJ/h, \quad (10)$$

where $q_{ng}$ – calorific capacitance of natural gas, $q_{ng} = 33.5\,MJ/m^3$.

The closest standard size of a natural gas boiler is KG-1 500 with a capacity of 1 500 kg of steam per 1 hour. When working on biogas, the heat power can be found by the following formula:

$$W_{bl} = 1\,500q_{ng}/C_b = 2\,380\,MJ/h \quad (11)$$

Operating time (per day) of the steam boiler for own needs

$$t_{ot} = Q_{ou}/W_{bl} = 4.2\,h$$

The technical and economic calculation is based on the benefits determining method, given the profit from the marketable biogas utilization, improving the manure fertilizing properties, and increasing the degree of its disinfection. For a year on a 400 heads farm, it is required to process 12.975 m3 of manure. It is known that 1 ton of well-prepared manure in burts increases the harvest of 100 feed units per crop rotation, and 1 ton of fermented manure is more effective than burt (increasing the harvest) by 10...15 %. Therefore, the harvest annual increase will be 13 * 10^4 feed units. At a cost of 1 food unit 8. this will give 10 400 rubles of profit.

The effect ($E_1$) of manure fertilizing properties improving and its disinfection is 52.547 rubles. To determine the overall benefits, a 400-animal farm with an aerobic manure decomposition system is used as the base farm. Manure flows into the pump sump, from where, as fecal pumps accumulate 4NF, it passes to the tanks for aerobic decomposition. The structure and facility costs is 144 thousand rubles. The machinery, facility, and structure costs for the new manure processing technology ($E_3$) more by 14,126 rubles than the base one.

The total benefit, given all component $E = E_1 + E_2 - E_3 = 52\,547 + 6\,388 - 14\,126 = 44\,809\,RUB$, where $E_2$ is the effect of marketable biogas utilization, RUB.

6. Conclusion

Methane digestion of manure in combination with the processing of biogas released into feed protein based on controlled microbial synthesis is a new production process that provides both energy and feed additives. The course of microbial synthesis in devices of different scales in terms of a unit volume of the amount of the obtained product (biomass or metabolic products) will be the same or almost the same
in devices of different scales. This technology makes it possible to implement an accelerated cycle of bioconversion of substances at a livestock enterprise parallel to the traditional path of their regeneration in crop production, which provides real opportunities for creating livestock complexes in the form of waste-free production that meets all the requirements of the economy and environmental protection. An analysis of the physical properties of manure after fermentation showed that the decomposition rate of absolutely dry ashless matter was 22% with a daily loading dose of 4.5%. Humidity of manure and its ash content after fermentation increase, which is explained by the partial expenditure of dry matter on the formation of biogas. Using experimental data on biogas yield and degree of decomposition of manure, the most effective doses of the average daily loading of the digester were determined. It was found that the maximum value of this indicator should not exceed 4.5 and 9% in the mesophilic and thermophilic modes, respectively. With an increase in the loading dose, the biogas yield decreases and the process is unstable. In this case, it is possible to ensure the biogas plants effective use on livestock farms and complexes, preserving the block-modular principle of building equipment sets.

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