Bioenergetics’ potential of the poultry and swine wastes in Belgorod region of Russia

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Abstract. Studies of biogas productivity of broiler chicken manure and fattening pig manure collected at the enterprises of Belgorod region of Russia were carried out. The specific yield of biogas from broiler chicken manure was 0.449±0.014 m³/kg of organic matter (oDM), methane specific yield – 0.256±0.008 m³/kg of oDM, from pig manure - 0.300±0.006 and 0.185±0.005 m³/kg oDM, respectively. The annual yield of these substrates in the region was calculated. The energy potential of substrates conversion into biogas was determined: the total yield of electric energy will be 9.339 billion kWh, heat energy - 10.322 billion kWh per year, or 25.585 and 28.279 million kWh per day, respectively.

1. Introduction

Modern intensive livestock breeding implies a high concentration of animals in a limited area. The increase in economic efficiency also has the negative consequence – production of large amounts of waste. Pig manure and poultry droppings should not be applied to the soil without pretreatment. The most common methods of its disposal are sedimentation in lagoons and composting. The main disadvantages are the following: increase in the greenhouse gas emissions into the atmosphere and demand in free space for waste storage. The processing of manure and its application in the biogas technology, despite its high cost, does not have these disadvantages. Thus it is possible to utilize substrates with both low and high dry matter mass fraction and to create their optimal combinations. In Russia for the production of biogas it is most reasonable to recycle the manure of farm animals, waste from processing enterprises of the agro-industrial complex, plant residues, etc. The use of these materials, which are already available and require recycling, is less expensive than the cultivation of renewable plant raw materials.

Planning and operation of biogas plants must be carried out in conjunction with the enterprises, whose waste is to be processed. In this way a practically closed system is created, the maximum use of resources (substrates and energy) is carried out, waste accumulation is minimized.

The formation of biogas is a process depending on a large number of factors. Even a slight change in one of the parameters can cause a change, or even a failure, in the operation of the system. Biogas productivity of substrates is also influenced by a regional factor, including natural and climatic conditions, traditionally grown species and breeds of animals, cultivated crops, animal feed rations,
economic features of the region, etc.

To evaluate the biogas productivity of substrates, as a rule, laboratory experiments in storage-type plants (Batch-systems) are carried out; as a result, the maximum biogas yield potential is determined.

The Belgorod region of Russia is the leader in the country in the production of pork and poultry, a negative consequence is the formation of a large amount of waste. To solve this problem, methods such as composting and waste conversion into biogas have been implemented. There are two biogas plants in the region, Baitursi and Luchki, with a capacity of 0.5 and 3.6 MW, respectively.

The Baitursi biogas plant (Regional Energy Company LLC) is a pilot project; it was assumed that its main raw material would be liquid pig manure from a local livestock farm. However, this substrate did not meet expectations - its composition was inconsistent. Due to the reason that requirements of the manure removal technology were not met, content of dry matter often did not exceed 1%, sometimes foreign solid objects and substances inhibiting the process of gas formation (mechanical inclusions, detergents, disinfectants) were found in the waste water. Therefore, the management of the biogas plant had to reject this substrate and switch completely to raw materials of plant origin.

Biogas plant Luchki (AltEnergo LLC) is engaged in disposal of waste of plant and animal origin. Constant substrates are liquid pig manure, slaughter waste, incubators’ waste, chicken manure, sugar beet and oil production waste, corn silage. Contracts are signed with enterprises for waste disposal.

The electricity produced by the biogas plants is sold to the grid and paid for by the energy company according to the “green” tariff. At the same time, the difference in the cost per unit of energy does not exceed the cost of losses when electricity comes to Belgorod Region from the Kursk nuclear power plant. According to the information from AltEnergo LLC, the amount of losses is about 10 MW in total. In the Belgorod region, alternative energy sources produce about 4.3 MW of electricity (including 0.2 MW produced by an experimental site with solar panels and wind turbines), so it is advisable to build more alternative energy facilities in the region with a total capacity of 5.7 MW.

To date, in Russia, the regulatory framework for green tariffs on the retail market has been adopted in Krasnodar and Krasnoyarsk regions, the Republics of Adygea, Bashkortostan, Moscow, Kaluga, Irkutsk, Orenburg, Astrakhan and Belgorod regions. Currently, negotiations are carried out to accept a base for green tariffs in the Tula, Ulyanovsk and Leningrad regions [1].

Today in Russia the design of biogas plants is based on the substrate characteristics given in the handbooks and manuals of the Office of Technology and Construction in Agriculture (KTBL), the manuals of the Renewable Feedstock Agency (Fachagentur Nachwachsende Rohstoffe e. V. (FNR)), etc., according to them, biogas plants are designed in Germany [2, 3]. Thus, regional peculiarities of Russian substrates, which can differ significantly from German ones, are not taken into account. This can have a negative impact on the operation of biogas plants.

The goal of this study is to determine the bioenergy potential of the most common wastes for biogas production in the Belgorod region of Russia.

2. Materials and methods
Litter-free manure from fattening pigs (animals 112 to 189 days old) and manure from broiler chickens after the growing cycle (up to 42 days old) with sawdust as bedding were used as research materials. All substrates were obtained from enterprises in the Belgorod region of Russia. Data on the number of pigs and poultry for the last calendar year were provided by the Department of the Agroindustrial Complex and Environmental Reproduction of the Belgorod Region.

Biogas productivity of substrates was determined using Hohenheim test of biogas yield according to [4, 5]. The substrates were pre-dried in a drying cabinet at +58 - +60°C for 48 hours and crushed to a particle size of no more than 1 mm. A weight of 0.4 g was placed in a sealed glass cylindrical flask-reactor with a 100 ml piston and 30 g of inoculum were added. Incubation of the substrates was carried out in a thermal cabinet at +37°C. Substrates were stirred by means of a rotor mounted in the thermal cabinet. Each substrate was investigated in three replicates, samples with inoculum without adding any substrate were used as a "zero" variant. Gas sampling was performed daily up to 4 times a day at the beginning of the experiment, then – according to the gas formation. The volume of biogas
was determined by reading the value on the flask scale, the composition (volumetric fraction of methane) - by infrared spectrometric sensor Advanced Gasmitter, "Pronova Analysetechnik" (Germany).

The mass fraction of dry matter (DM) and organic matter (oDM) in substrates were determined according to [6].

To ensure the comparability of the results of the study, the gas volume was reduced to normal conditions according to equation 1:

\[ V_0 = \frac{P \times V \times T_0}{T \times P_0} \]

where:
- \( V_0 \) – volume of dry gas under normal conditions, ml;
- \( V \) – measured gas volume, ml;
- \( P \) – gas pressure at the time of measurement, mbar;
- \( P_0 \) – atmospheric pressure at normal conditions; \( P_0 = 1013 \) mbar;
- \( T_0 \) – air temperature at normal conditions; \( T_0 = 273 \) K;
- \( T \) – biogas temperature, K.

The materials were processed by the method of variation statistics using Microsoft Excel. The data are presented as mean value and statistical error.

3. Substrates' biogas productivity study

The main analyzed parameters of feed substrates are the mass fraction of dry matter and the mass fraction of organic matter - this determines the volume of feedstock loading rate into the bioreactor and the expected biogas and methane yield, and, consequently, the amount of energy to be obtained.

The content of dry matter and organic matter in animal and poultry excreta from different plants can vary greatly. For example, in the studies of Cu Thi Thien Thu et al. [7] used pig manure with a higher mass fraction of DM (37.01 %) than in our experiment (Table 1), but the mass fraction of oDM in it was lower (75.82 %). Other authors studied manure with WS content from 4.21 to 32.80 %, oDM content varied from 59.0 to 84.0 % [8, 9, 10, 11, 12, 13].

In the planning and operation manual of FNR, biogas plants in the substrate characteristics section pig manure with WS and oWS content of 20 - 25% and 75 - 80% respectively is given [14], which is close to the values of the corresponding indicators in our experiment.

In our experiment, chicken manure contains more dry matter and organic matter than in the FNR manual (according to FNR, the content of DM in the droppings is 32.00%, oDM - 63.00 - 80.00%) [14]. If we compare the values obtained by us with the results of the experiments of other authors, in most cases their research material contains more dry matter - from 68.00 to 83.80 % [15, 16, 17, 18, 19], but less organic matter - from 48.09 to 82% [15, 16, 19, 20, 21], except for the materials of T. Böjti et al. (95.87 % oDM) [18].

![Table 1. Composition of initial substrates and their biogas productivity](image)

| Substrate                  | Mass share of dry matter (%) | Mass share of organic dry matter (% DM) | Specific biogas yield (m³/kg oDM) | Specific methane yield (m³/kg oDM) |
|---------------------------|------------------------------|----------------------------------------|---------------------------------|-----------------------------------|
| Manure of broiler chicken | 58.13±1.29                  | 92.17±0.01                             | 0.449±0.014                    | 0.256±0.008                      |
| Swine manure              | 23.80±0.15                  | 78.94±0.45                             | 0.300±0.006                    | 0.185±0.005                      |

Biogas productivity of pig manure in our experiment is in line with the values given in the FNR manual (specific biogas yield – 0.270 – 0.450 m³/kg oDM; specific methane yield – 0.162 – 0.270 m³/kg oDM) [14], but it is still closer to the lower boundaries of the given range. The specific biogas yield in our experiment is lower than in the studies of Vo Chau Ngan Nguyen et al. (2013) and Yu et al. (2017) [10, 13], but higher than E. Trosigård (2015) and Yin et al. (2015) [11, 12]. The values obtained by these authors are 0.400, 0.370 to 0.600, 0.111, and 0.047 to 0.266 m³/kg oDM,
respectively. In terms of specific methane yield, the manure studied in our experiment exceeds the results obtained by Cu Thi Thien Thu et al. (2013), E. Trosgård (2015), and Yin et al. (2015), which are 0.177, 0.037, and 0.025 to 0.074 m³/kg oDM, respectively [7, 11, 12]. In studies by Yu et al. (2017) pig manure had a higher specific methane yield of 0.259 to 0.450 m³/t oDM (i.e., methane content in biogas was 70.0 to 75.0 %) [13]. Methane content in biogas from pig manure in our experiment was 61.67 %.

Biogas productivity of chicken manure in studies of different authors varies significantly, the specific yield of biogas ranges from 0.018 to 0.940 m³/kg oDM [15 - 24]; it should be noted that in these studies both litterless manure and littered manure were used as a studied material; cofermentation of manure with other co-substrates also takes place; different fermentation systems and modes are used: one- and two-stage systems, different thermal operation modes, duration of experiment was varied, etc. Thus, in the studies of M.R. Miach et al. the specific biogas yield from chicken manure with bedding was 0.263, m³/kg oDM [22], and in research of I.M. Alfa et al. - 0.940 m³/kg oDM [15]; methane concentration was 71.00 and 61.71% respectively. In the experiments of T. Dalkilic et al. when processing substrates in single-phase system, the specific biogas yield was 0.459 to 0.517 m³/kg oDM, in two-phase system - 0.356 to 0.386 m³/kg oDM [20]. When processing manure in semi-continuous mode, the specific yield of biogas was 0.554 m³/kg of oDM, and specific methane yield was 0.410 m³/kg of oDM [23].

Relatively low biogas productivity was shown by the substrate in bioreactors with recirculation of contents (specific biogas yield - 0.183 m³/kg oDM, methane - 0.074 m³/kg oDM) [17], in multi-stage high-speed fermentation regime (specific methane yield – 0.160 m³/kg oDM) [24] and in processing of dried chicken manure solution (specific biogas yield – 0.210 m³/kg oDM) [18]. The lowest biogas productivity of manure was found in the works of K.C. Dornelas et al.: specific biogas yield in different variants was from 0.018 to 0.043 m³/kg oDM [19]. Thus, with respect to specific biogas yield and specific methane yield the broiler chicken manure studied by us occupies an intermediate position in comparison with the results obtained by other authors and in comparison with FNR data (specific yield of biogas – 0.250 – 0.450 m³/kg oDM, methane – 0.150 – 0.270 m³/kg oDM) and is within the maximum values given in this guide [14].

Chemical analysis of substrates and determination of their biogas productivity under laboratory conditions are important stages in the design of industrial biogas plants. The data obtained (dry matter and organic matter content, biogas and methane yield per unit of organic matter) are used to calculate the volume of the bioreactor, the biogas plant gas tank and technical parameters of the energy generating equipment. Based on the biogas potential of substrates, it is possible to calculate the amount of electrical and thermal energy that can be produced by substrate processing.

To determine the excrement yield, we used reference data: 1 broiler chicken excretes on average 0.12 kg of manure daily, 1 pig - about 7.0 kg of excrements [25, 26]. To calculate the total methane yield and organic matter, we used the data obtained in our experiments (Table 2).

| Animals              | Livestock (mln. animals) | Excrement yield per year (thousand tons) | oDM annual output (thousand tons) | Annual methane output (thousand m³) |
|----------------------|--------------------------|----------------------------------------|----------------------------------|-------------------------------------|
| Pigs                 | 4542.4                   | 11605.783                              | 38494141                         | 7121416.0                           |
| Broiler chicken      | 51155.1                  | 2614.026                               | 4144757                          | 1094215.9                           |
| Total                |                          | 14219.809                              |                                  | 8215631.9                           |

Thus, the annual methane yield due the processing of excrements of fattening pigs and broiler chickens in the Belgorod region could be more than 8.2 billion m³.

When determining the yield of electric energy, it was taken into account that 1 m³ of methane during combustion gives 9.971 kWh of energy. On average, the efficiency factor (coefficient of
performance) of the combustion engine operating on biogas is 30%. About 38% of the energy produced is converted into electricity and it can be fed into the energy grid, and about 42% is converted into heat energy. Thus, the annual energy output in the region in total can reach 81.918 billion kWh, and taking into account the efficiency of the engine - 24.575 billion kWh. In this case, electric and thermal energy output will be 9.339 and 10.322 billion kWh per year respectively, or 25.585 and 28.279 million kWh per day.

4. Conclusion
Biogas productivity of fattening pigs’ manure obtained at the enterprise in Belgorod region of Russia occupies an intermediate position compared to the results obtained by other authors in different countries. In comparison with the data from the guidelines for planning and operating biogas plants FNR, the values of bioenergetic potential of manure from Russia are close to the lower limits of the given interval. In our experiment, the specific biogas yield was $0.300\pm0.006 \text{ m}^3/\text{kg oWS}$, and the specific yield of methane was $0.185\pm0.005 \text{ m}^3/\text{kg oWS}$.

The broiler chicken manure used in our experiment contains more organic matter, and in terms of specific biogas and methane yield it occupies an intermediate position, compared with the results of studies obtained by other scientists. Compared to the substrate described in the FNR manual, the substrate we studied contains much more dry matter and organic matter, and its biogas productivity is close to the upper limits of the range of values given in the FNR manual. Specific biogas yield from broiler chicken manure obtained in the conditions of the Belgorod region of Russia was $0.449\pm0.014 \text{ m}^3/\text{kg oWS}$, specific methane yield was $0.256\pm0.008 \text{ m}^3/\text{kg oWS}$.

It was found that in the Belgorod region of Russia, about 14.220 million tons of broiler chicken manure and pig manure is produced annually (in natural mass). As a result of its conversion into biogas, the energy output could be about 9.339 billion kWh of electricity and 10.322 billion kWh of thermal energy annually, or 25.585 and 28.279 million kWh daily respectively.

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