Implementation of poultry waste disposal technology for energy and fertilizer production

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Abstract. The developed unit, which implements the technology of separation of raw materials into useful components by thermal destruction, makes it possible to obtain fuel synthesis gas, in which carbon monoxide (CO) and hydrogen (H_2) predominate, suitable for use in internal combustion generators for generating electrical energy, as well as saturated ash potassium (K) and phosphorus (P) suitable as a fertilizer in agriculture.

1 Introduction

Poultry farming is one of the most important and profitable sectors of animal husbandry in the Russian Federation, since the production of poultry products is characterized by a short reproduction cycle and a quick return on investment [1]. However, when breeding poultry, there is a problem of ensuring environmental safety in the disposal of waste from poultry enterprises. At present, poultry manure during preliminary preparation is allowed to be used on agricultural land as an organo-mineral fertilizer. However, poultry waste is a source of secondary resources that can be used to generate energy. For these purposes, various gasification plants operating on various raw materials are used, and the ash is suitable for use as a mineral fertilizer with a high content of phosphorus and potassium [2–4].

2 Materials and methods

All research to find the best engineering solutions for the disposal of poultry waste was carried out in 3 stages, including:

- Mathematical modeling of processes occurring in the volume of the gasification plant.
- Creation of an experimental facility to verify the reliability of the adopted regime and design solutions.
- Laboratory analyzes of ash after gasification for suitability as a fertilizer

In theoretical studies of the processes and designs of gasification plants, mathematical modeling methods were applied, the basics of the method of the chemical equilibrium state of the reacting system were used using software systems installed on a personal computer. Experimental studies were carried out on the basis of state standards (GOST) and

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regression analysis of the data obtained using the EXCEL and MatLab programs, laboratory analyzes were performed in an accredited laboratory using GOSTs and federal regulatory environmental documents (PNDF) [5].

The choice of reactions for modeling gasification processes in which the maximum yield of synthesis gas with high calorific value is achieved was based on the following reactions [6]:

- $2C + O_2 = 2CO$ (partial oxidation reaction).
- $C + O_2 = CO_2$ (complete oxidation reaction).
- $C + 2H_2 = CH_4$ (hydrogasification reaction).
- $CO + H_2O = CO_2 + H_2$ (water gas shift reaction).
- $CH_4 + H_2O = CO + 3H_2$ (steam reforming reaction).
- $C + H_2O = CO + H_2$ (water gas reaction).
- $C + CO_2 = 2CO$ (Boudouard reaction).

These reactions are also taken into account in their models by Beheshti, S.M. [7], Ajay, K. [8].

The reaction rate constants were selected from the database of The National Institute of Standards and Technology (NIST), which includes almost all published results of the kinetics of thermal gas-phase chemical reactions [9-10].

The approach chosen to calculate the process of gasification of poultry waste is based on the equilibrium constant, which is an advantage in modeling the equations of thermochemical equilibrium [11-15]. The combination of the laws of conservation of energy in an open system of conservation of atomic species and the laws of chemical equilibrium provide a numerical algorithm that can be used to predict the composition of syngas and investigate the influence of important variables on gasification performance. This model has the following goal: to calculate the desired key parameters of synthesis gas in biomass gasification, such as maximum efficiency, calorific value, optimal gasification temperature, etc. [16].

The mathematical model is described by the system of equations:

The composition of gasification products and the factors affecting it is represented by a system of equations:

$$\begin{aligned} d\gamma_i^z/d\tau = & -\exp\left(\gamma_i^z\right)\left[\sum_j v_{ij}\Omega_j^z + S_{iz} + R_0 T_z/p_z - S_{iz} - \exp\left(-\gamma_i^z\right)\right] + \\ & + \sum_q \left[\sum_j v_{qj}\Omega_j^z + S_{qz} + R_0 T_z/p_z - S_{qz} - \exp\left(-\gamma_q^z\right)\right] \end{aligned} \quad (1)$$

A complex that takes into account the energy flows brought in and taken out of the volume of the gasification plant with the flows of individual components:

$$B_z = \sum_j \left(\sum_k m_i^{s,z} h_i^s + m_i^{z-1,z} h_i^{z-1} + m_i^{z+1,z} h_i^{z+1} - \sum_s m_i^{z,s} h_i^z + m_i^{z,z-1} h_i^z + m_i^{z,z+1} h_i^z\right. \quad (2)$$

The equation for the change in the specific mass enthalpy of the gas mixture in the volume of the gasification plant:

$$dh_z/d\tau = \left\{\sum_j m_{j,z}^{+}\left(h_j - h_z\right) + \sum_k \left[m_{k,z}^{+}\left(h_k^{+} - h_z\right) + m_{k,z}^{-}\left(h_z - h_k^{-}\right)\right] + C_z + V_z\left(dp_z/d\tau\right)\right\}/M_z \quad (3)$$

Mixture temperature equations:

$$T_z - T_{on} - \left[h_z \mu_z - \sum_i H_i^{on} r_i^z \right] / \sum C_{pi}^{on} r_i^z = 0 \quad (4)$$

The system of equations (1-4) is open to be supplemented by other equations that describe the change in any parameters due to processes characteristic of specific gasification schemes [17-18].

The experimental part of the research consisted in developing the design of a gasification plant in which the process should be carried out at high temperatures and with controlled reactions. At the same time, air inflow and losses to the environment are not allowed.

In the process of searching for the best engineering and design solutions, taking into account all the advantages and disadvantages, a new gasification unit was developed (Patent of the Russian Federation for the invention No. 2,754,911 dated 09/09/2021), which is aimed at increasing the efficiency of syngas generation. The task was to create such an installation, where in the same volume, when using a steam gasification agent, drying and thermal destruction of the loaded raw materials take place.

In this case, the heating of the loaded raw material is carried out from an external source with a conductive heat supply. The installations most corresponding to these criteria are [19-26].

As a result of the research, a gasification plant was developed (figure 1).

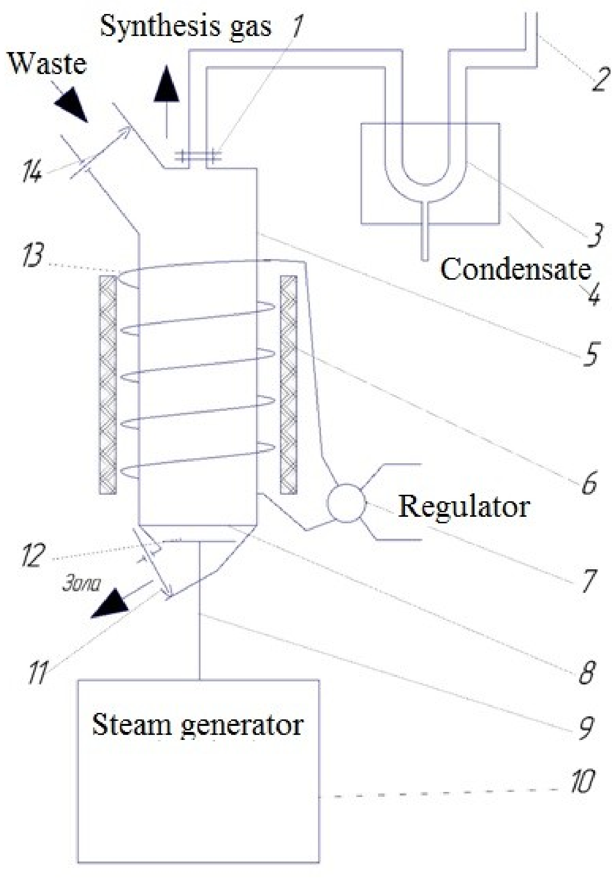

Figure 1. Manure gasification plant: 1 – synthesis gas outlet fitting; 2 - branch pipe for the removal of synthesis gas; 3 - condensate drain; 4 - capacitor; 5 - body; 6 - heat-insulating material; 7 - voltage regulator; 8 - grate; 9 - collector; 10 – steam generator; 11 – unloading damper; 12 - steam supply nozzles; 13 - electric heater; 14 - loading gate.

Case *1*, in which there are no moving parts. In the upper part of the housing there is a loading damper *14* and an outlet fitting of synthesis gas *1*, and in the lower part there is a grate *8*, steam supply nozzles *12* and an unloading damper *14*. Steam is produced in the steam generator and is supplied through the collector *9*. The housing is heated from the electric motor *13*. The temperature is set using a voltage regulator *7*. To reduce losses to the environment, the gasifier is externally covered with a heat-insulating material *6*, in the upper part there is also a condenser *4* with a condensate trap *3* and a branch pipe for removing synthesis gas *2*.

The use of the proposed installation will allow:

- Reduce the emission of greenhouse carbon dioxide (CO_2) due to the endothermic reaction, accompanied by the formation of carbon monoxide (CO).
- Reduce environmentally harmful nitrogen oxide (NO_2) in synthesis gas, since there are no impurities inherent in atmospheric air and exhaust gases in the gasification zone.
- Reduce the suction of atmospheric air, which contributes to a more precise regulation of the process, which is achieved by eliminating moving elements inherent in similar structures.
- To increase the calorific value of synthesis gas due to the exact calculation of the required number of moles (molecular and atomic) of the gasifying agent and the known number of moles of components in the raw material.

The product obtained after waste gasification (ash) was subjected to laboratory analysis in an accredited environmental and chemical laboratory for the possibility of using ash as a fertilizer.

3 Results and Discussion

Based on the results of theoretical and experimental studies of the developed experimental sample of a gasification plant with a coarse and fine purification system for using the resulting synthesis gas in internal combustion engines (ICE) to produce electrical energy (EE), studies were carried out on the composition of the concentration of combustible components.

Measurements of the concentration of combustible components (figure 2) of the synthesis gas were carried out for the main components, including hydrogen, carbon monoxide and methane. Values are given in grams per kilogram of gas produced.

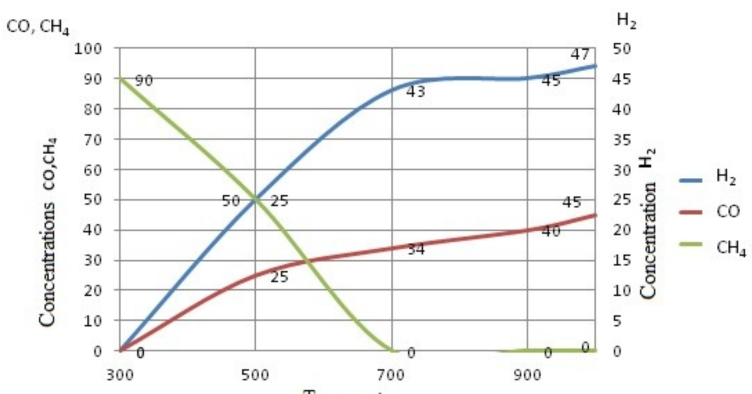

Fig. 2. Results of experimental studies on measuring the concentration of combustible components.

According to the reactions described in [6], we note that the produced methane at high temperatures is converted into hydrogen (H_2) and carbon oxide (CO), thereby not reducing its high fuel properties.

The results of experimental data with calculations are shown in the form of diagrams with a 5% confidence interval for carbon monoxide (CO) - in figure 3.

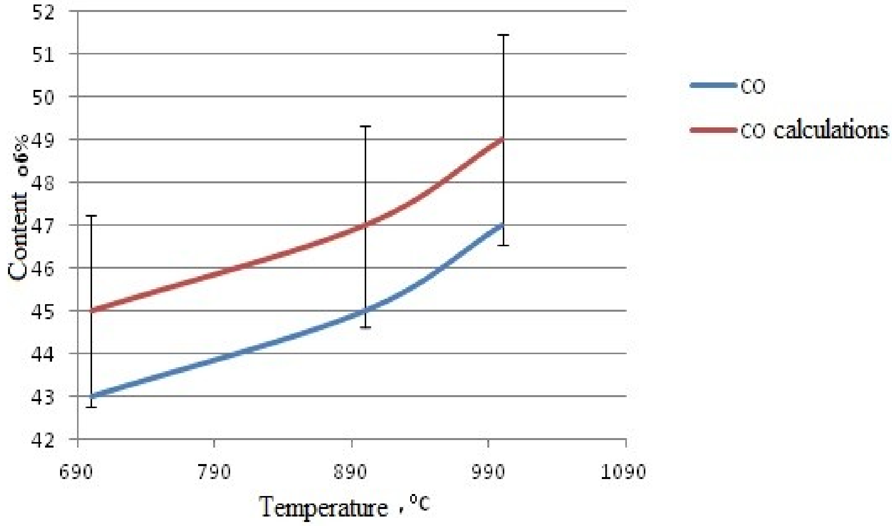

Fig. 3. Graph of comparison of calculated and experimental data for carbon monoxide (CO).

The results of experimental data are compared with the results of theoretical studies. The results are given with a confidence interval of 5%.

According to the results of the analysis for hydrogen (H_2), the results of the experiments are consistent with theoretical studies (figure 4).

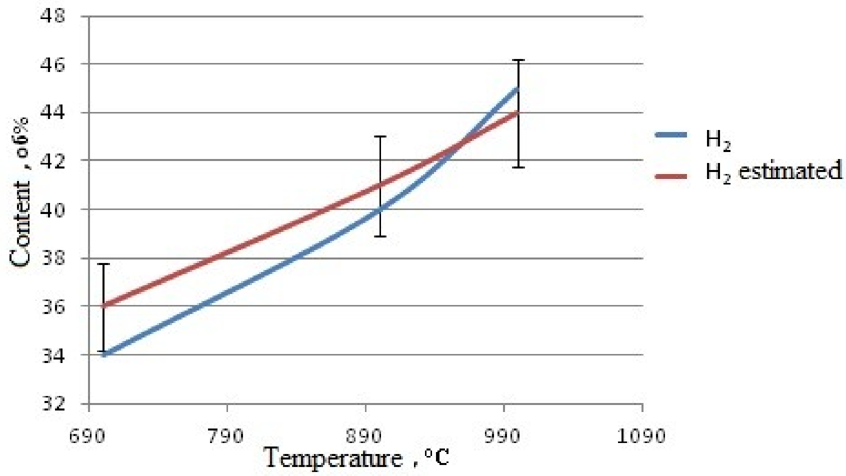

Fig. 4. Comparison graph of calculated and experimental data for hydrogen (H_2).

The results of a series of experiments carried out using steam as a gasifying agent show agreement with theoretical mathematical calculations.

The ash formed during the gasification of manure is 20% by weight of the feedstock. The resulting ash contains potassium oxide (K_2O) - 15.5%, phosphorus oxide (P_2O_5) - 23.9%, calcium oxide (CaO) - 17%. Pathogenic microflora is completely destroyed.

4 Conclusion

A gasification plant was developed and manufactured, the novelty of the technical solution of which is protected by a patent for invention No. 2754911. On the basis of theoretical calculations, the main design and technological parameters of the plant are substantiated: height - 0.7 m, diameter - 0.1 m, weight without load - 50 kg.

A mathematical model (1) - (4) of the gasification process has been developed, it describes the complex nature of chemical reactions in the volume of a gasification plant,

The environmental effect from the introduction of the gasification plant made it possible to reduce payments for waste disposal of 3-4 hazard classes and amounted to 1 million 328 thousand rubles a year.

The economic effect from the introduction of a gasification plant with the recovery of poultry waste is 148,952.96 rubles. The payback period of the proposed installation is 1.36 years.

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