Conference Paper

Optimization of the Cremator Settings for the Disposal of Poultry Waste By Incineration in a Beet-emitting Boiler

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Abstract

The purpose of this work is to substantiate the parameters of the boiler unit, which ensures the cremation of manure using microwave radiation. The substantiation of the amount of heat released during the burning of chicken manure at the industrial keeping of poultry in the conditions of sharply continental climate on the basis of minimization of product utilization values - ash content of wastes and pollution of smoke emissions is presented. Using the obtained regression models of magnetron emission power, moisture content of the burnt manure mass, mass air consumption for the specified product utilization parameters, the analysis of the relationship between the obtained parameters is made. Correlation analysis has shown a high correlation between the amount of heat released during the combustion of manure and the concentration of carbon monoxide in the smoke emissions. Rationally, the value of carbon monoxide content in the flue gases is 3.9%, corresponding to the amount of heat released 2.1 MJ/kg at the combustion of a kilogram of manure at the ash content of the residue of 18.4% and the initial moisture content of the manure of 38.4%. It provides power of radiation of magnetron 400 W on 1 kg of a waste and the mass flow rate of air of 13.8 kg/h.

Keywords: chicken excrement, poultry waste disposal, waste incineration, ash residue, microwave radiation

1. Introduction

Modern technologies for recycling waste from agricultural enterprises provide for economically viable biological methods of processing manure and crop residues [1--3]. In this case, waste is disposed of and organic fertilizers are formed, which are used to increase soil nutrition [4--6]. In the processing of municipal, agricultural and industrial wastes, they tend to allocate an organic fraction for biological processing, and minimize the share of incinerated residues [7--10]. However, in contrast to the warm climatic zones of human habitation, where biological disposal of waste is possible, in Russia there are zones with low temperatures, where the provision of living conditions for living organisms that process waste, economically and technologically unprofitable.

In the cold climatic conditions of the sharply continental climate of the Republic of Buryatia, cremation of chicken manure in specialized boilers remains a technologically justified method of utilization of chicken manure [11, 12]. In order to increase the efficiency of the cremation process it was suggested to additionally use microwave emitters [10] in the design of boilers, which contribute to the increase of energy of fuel mass burning activation on the basis of manure [13, 14]. In theoretical and experimental studies of the dependence of the manure cremation process on the design parameters of the cremator with a microwave emitter and the technological characteristics of the fuel mass, it became clear that there are a number of optimal values of optimization criteria, which subsequently gives uncertainty in the choice of equipment settings [12].

The purpose of this work is to substantiate the parameters of the boiler unit, which ensures the cremation of manure using microwave radiation. Criteria for optimization of the manure cremation process were chosen as the object of the study: the amount of heat released during the combustion of Q1, J (Y1) manure; AP ash content, % (Y2); carbon monoxide concentrations in the smoke emissions φ, % (Y3). The subject of the study is the interrelation of optimization criteria. In order to achieve the set goal, it is necessary to solve a number of tasks:

to analyze the interrelation of criteria for optimizing the process of manure cremation on the basis of theoretical mathematical model;

1. to construct a structural model of interrelation of optimization criteria taking into account the influence of external factors in the form of radiation power of magnetron P_inh,W; moisture of litter mass used as fuel W, %; mass flow rate of air L, kg/h;
2. to evaluate quantitatively the degree of interrelation of optimization criteria on the basis of analysis of experimental data;
3. to present a graphical model of interrelation of optimization criteria with indication of their optimal values and subsequent selection of one rational one.

The working scientific hypothesis is that the rational values of the optimization criteria Y, with their number N = 3, are located on the response surface of the function Y3 = f(Y1,Y2) in the area closest to the line, passing through the center of coordinates and equidistant from the axes x,y,z.

2. Methods and Equipment

2.1. Methods

The mathematical model of the manure cremation (combustion) process in the boiler unit with the use of microwave energy was based on the known equation of thermal balance [14, 15, 16] and finally represents the dependence of the optimization criterion $Y_1(Q_1)$ from the aggregate of the variable values of the factors X1- of the magnetron emission power P_m, W; X2 - the moisture content of the litter mass used as fuel **W**, %; X3 - mass flow rate **L**, kg/h and optimization criteria Y2 (**A**, %), Y3 (φ_{co}, as well as a number of other characteristics [1].

$$Q_1 = 13936.3232 - 165.5174W + 149.0854L + C_r F \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] + C_{mc} t_l + C_a L t_a + P_m (1 - e^{\left(-\frac{1}{4\sqrt{15\sigma\upsilon\left(1-\upsilon^2\right)}} \left(1+2\frac{b}{a}\upsilon^2\right) \cdot \frac{1}{b\sqrt{a}} \right) l}) \tau) - (H_{fg} - \alpha_{fg} H_{ca} + m_p \rho_p (126,4\ \varphi_{CO} + +358\ \varphi_{CH_4} + +107,9\ \varphi_{H_2}) + a_r A^P \frac{G_{r.} Q_{c.}}{1 - G_{r.}} + A^P a_s (Ct)_s + + \frac{m_{\Pi} \rho_{\Pi}}{1 - \frac{W}{100}} (C_{whater} \left(t_2 - t_l \right) + L_{heat}) \quad (1)$$

where: C_r, W/(m^{2}K^4) - the radiation factor given for the two opposing bodies, which in this case means the parts of the burning and not yet burning fuel in the form of manure, $C_r = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} - \frac{1}{C_0}}$; F-radiation surface area, m^2; T_1, T_2 - absolute temperatures of heated and heated bodies, *K*; C_1-is the coefficient of emission of the burning part of the fuel mass, W /(m^{2}K^4); C_2-is the coefficient of radiation of the smoldering part of the fuel mass, W/(m^{2}K^4); $C_0 = 5,68$ W/(m^{2}K^4) - the emission factor for the blackest parts of the fuel cell; C_{mc} - manure heat capacity; t_l -- initial litter temperature as fuel; C_a - specific heat of air; t_a -- air temperature, °C; P_{in} -- the input power of the magnetron on the waveguide, W; α - attenuation coefficient; l - the length of the waveguide, m; σ - conductivity of waveguide wall material, Ohm/m; υ - wave velocity, m/s; H_{fg} - flue gas enthalpy, kJ/kg; H_{ca}- cold air enthalpy, kJ/kg; α_{fg} - is the excess air ratio of the flue gases; where a_r - fraction of ash fraction removal from the furnace with combustion products, %; A^P - operating ash content, %; G_r - combustibles in products carried away by the gas flow; $Q_c = 32,6\ MJ/kg$ - estimated heat of coke residue combustion in the carryover; a_s - slag fraction,%; $(Ct)_s$ - slag enthalpy as a product of its heat capacity and temperature; C_{water} - water heat capacity, kJ/kg·°C; t_2- steam generation temperature, °C; L_{heat} - Specific heat of vaporization, kJ/kg; φ -- fuel content in the mixture (in volume %).

To confirm the chosen theory, experimental studies were carried out, as a result of which the equations of regression of optimization criteria Y1, Y2, Y3 from factors X1, X2, X3 [2]:

$$Y_1\left(X_1, X_2, X_3\right) = 3.508 + 0.485 \cdot X_1 + 3.184 \cdot X_2 + 0.246 \cdot X_3 + 0.214 \cdot X_1{}^2 + 1.923 \cdot X_2{}^2 + 0.208 \cdot X_3{}^2 - 0.035 \cdot X_1 \cdot X_2 + 0.29 \cdot X_1 \cdot X_3 - 0.024 \cdot X_2 \cdot X_3 \quad (2)$$

$$Y_2\left(X_1, X_2, X_3\right) = 19.836 + 3.779 \cdot X_1 + 1.703 \cdot X_2 + 16.66 \cdot X_3 + 2.659 \cdot X_1{}^2 + 1.622 \times X_2{}^2 + {} + 2.566 \cdot X_3{}^2 + 1.351 \cdot X_1 \cdot X_2 - 0.317 \cdot X_1 \cdot X_3 - 0.155 \cdot X_2 \cdot X_3 \quad (3)$$

$$Y_3\left(X_1, X_2, X_3\right) = 5.222 + 0.501 \cdot X_1 + 2.93 \cdot X_2 + 0.113 \cdot X_3 + 0.386 \cdot X_1{}^2 + 1.644 \cdot X_2{}^2 - 0.331 \times X_3{}^2 + 0.536 \cdot X_1 \cdot X_2 + 0.445 \cdot X_1 \cdot X_3 - 0.37 \cdot X_2 \cdot X_3 \quad (4)$$

Equation correlation coefficients (2-4) are within $R \in (0.95; 0.99)$ [12].

2.2. Methods

From the mathematical point of view, the interrelation of optimization criteria (Y) and factors (X), taking into account the internal interrelations between criteria, can be represented in the form of some function, subordinated to the principles of equations with shared variables:

$$Y1\,(Y2, Y3, X1, X2, X3) = f\,(Y1, Y2) = f(F1\,(X1, X2, X3)\,, F2\,(X1, X2, X3)) \quad (5)$$

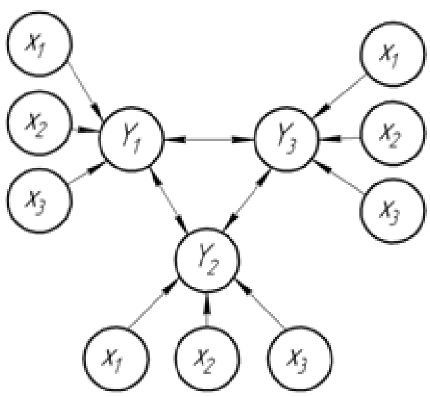

Figure 1: Structural scheme of interrelations between optimization criteria and factors for the theoretical model of the chicken litter cremation process.

2.3. Quantitative assessment of the degree of interrelation of optimization criteria

Quantitative assessment of the degree of correlation between optimization criteria was made by analysis of correlation coefficients. As a result, it was found that the greatest relationship (R=0.97) is between the amount of heat released from litter combustion (Y1) and the concentration of carbon monoxide in the smoke emissions (Y3). The relationship between the other criteria is weak.

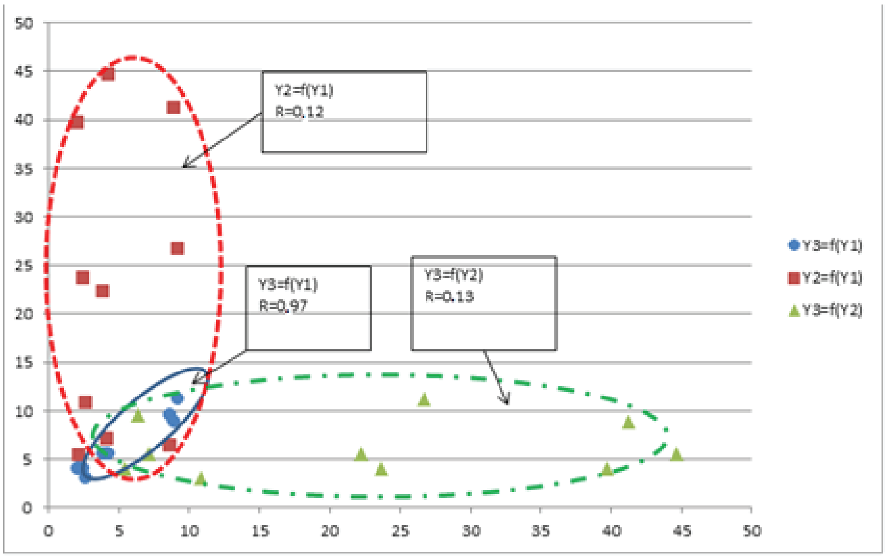

Figure 2: Comparative graphs of dependencies of optimization criteria, showing their interrelation.

On the basis of the conducted correlation analysis, the Y3 criterion is used as the z-axis for the construction of the response surface, since this choice of dependence of the carbon monoxide concentration on the heat release during fuel combustion is more logical.

2.4. Graphical interpretation of the relationship between optimization criteria

On the basis of a full-scale experiment, the optimum optimization criteria were identified (Table 1) [12].

The following software package was used to present the graphic material SPSS-SigmaPlotv.12. Analyzing the graph of the dependence of the optimization criterion Y3 on Y1, Y2, we can conclude that the rational value of carbon monoxide content in flue gases corresponds to Y3=3.91%, at Y1=2.105 MJ and Y2=18.398%.

Table 1: Optimal values of optimization criteria (the index of the implemented process) and the corresponding values of the factors under study.

Factor designation			X1, W	X2, %	X3, %
Criterion label	Name of the criterion	Optimal value of the criterion Y	Radiation power of mag-netron, W	Humidity of the litter mass to be burned, %	Mass flow rate, kg/h
Y1	the amount of heat emitted by the burning of manure, J	2.105	400	38.36	13.84
Y2	ashcontent A, %	18.398	141.6	49.88	26.585
Y3	carbon monoxide concentrations in flue gas emissions φ, %	4.056	400	38.6	39.13
		5.076	184.4	55	22.776
		3.916	386.4	37.28	26.585

3. Results

Rationally, the value of carbon monoxide content in the flue gases is 3.9%, corresponding to the amount of heat released 2.1 MJ/kg at the combustion of a kilogram of manure at the ash content of the residue of 18.4% and the initial moisture content of the manure of 38.4%. It provides power of radiation of magnetron of 400 W on 1 kg of a waste and the mass flow rate of air of 13.8 kg/hour.

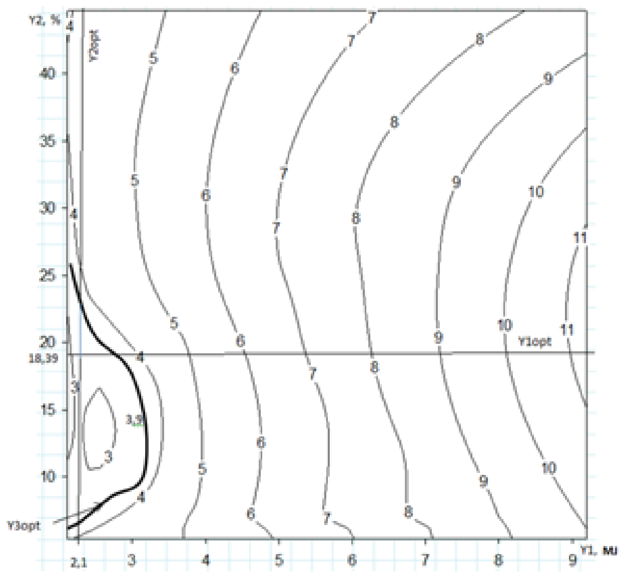

Figure 3: Graph of dependence of optimization criterion Y3 on Y1, Y2.

At this value, the optimization criteria vary in the following ranges: X1∈ (386.4; 400), X2∈ (37,28; 38.36), X3∈ (13.84; 26.585).

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4. Discussion

1. As a result of the conducted research on the development of methods for selecting the most rational value of the criteria for optimizing the process of manure cremation using microwave radiation from a number of points corresponding to the optimum was made;

2. From the mathematical point of view the interrelation of optimization criteria (Y) and factors (X), taking into account the internal interrelations between the criteria for the theoretical model of the fuel combustion process on a litter basis, can be presented in the form of some function, representing the equation with the separating variables;

3. The structural scheme of interrelation of optimization criteria is developed taking into account the influence of external factors in the form of radiation power of magnetron P_inh,W; moisture of litter mass used as fuel W, %; mass consumption of air L, kg/h;

4. Correlation revealed that the greatest correlation (R=0.97) is observed between the amount of heat produced by burning manure (Y1) and the concentration of carbon monoxide in the smoke emissions (Y3). The relationship between the other criteria is weak.

5. Analyzing the graph of the dependence of the optimization criterion Y3 on Y1 and Y2 it can be concluded that the rational value of carbon monoxide content in flue gases corresponds to Y3=3.91%, at Y1=2.105 MJ and Y2=18.398%.

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