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UPGRADING EXPERIMENTAL TECHNOLOGICAL LINES FOR OBTAINING BIO-FERTILIZERS FROM POULTRY BIOWASTE

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ABSTRACT

At this stage of work, a pilot line has been prepared for bioconversion of poultry waste with the optimum process parameters of temperature of 37°C, pH of 7.5 and duration of 12.0 hours, which includes the following: a conveyor for poultry waste; a disperser; a sterilizer; a nutrient medium mixer; a column for continuous sterilization of the nutrient medium flow; a holder heat exchanger; seed tanks; and an experimental fermentation reactor. The configuration of the process areas of the pilot line for biofertilizer production from poultry waste has been optimized, and three experimental batches of biofertilizers have been obtained in implementation of three equipment configurations. It has been found that all tested equipment configurations in the pilot line are capable of obtaining biofertilizers from poultry waste that meet the requirements of current normative documents in terms of physico-chemical, microbiological and safety criteria.

Keywords: poultry waste, bioconversion, destructor microorganisms, pilot line, process parameters, technological process.

INTRODUCTION

The problem of agricultural waste disposal, which include poultry waste [1] and its effective use is a transcontinental problem [2]. Inappropriate disposal of poultry litter pollutes the environment, depletes soil as a result of global chemicalization of agriculture, etc. [3, 4, 5]. The most popular method of disposing of such waste is composting [6]. However, this method is expensive, energy-intensive, unfriendly to the environment, and often does not meet the requirement to the agriculture and livestock [7, 8].

The solution to the problem of environmental pollution with poultry and livestock waste shall be focused on solving the following basic tasks [4, 9]:

- ensuring biological safety;
- ensuring environmental safety;
- obtaining useful products (proteins, fat, biologically active substances, etc.);
- production of feed additives for agricultural animals;
- energy production; and
- production of biofertilizers.

Production of biofertilizers is one of the most urgent tasks in modern agriculture [10].

Providing full-fledged biofertilizers for the population is inextricably related to the rational and economical use of their resources with regard to the existing processing infrastructure and the nature of poultry waste [7].

Cattle breeding are undoubtedly the main source of biological fertilizers to be used in agriculture of highly developed countries. However, without diminishing the role and significance of beef, pork [11], lamb, milk, and fish production waste, special attention is paid worldwide to the role of poultry waste in resolving the problem of providing biofertilizers of animal origin to the population. The share of the poultry sector in meat production in Russia is 1.2 million tons per year. It generates 0.4 million tons of poultry waste, which is a significant problem for the processing industry [6, 7].

Currently, due to intensive development of the biotechnological methods, processing poultry waste is promising with the use of the biological methods [12] that are not widely used for a number of reasons. In this case, the use of aerobic and anaerobic microbial conversion (bioconversion) of cattle breeding waste defines both the sanitary condition of the area around the livestock breeding buildings and poultry farms, and obtaining a sanitized, humified organic product of high biological activity without specific smell [13].

The microbial biotechnology can use huge masses of liquid and dense agricultural waste of plant and animal origin [14] for the production of feed preparations and additives. There is a wide range of microorganisms capable of transforming liquid and solid waste into feed preparations with formation of microbial biomass. The most promising producers are fast-growing microorganisms [13, 15].

The evident advantage of bioconversion over other methods is that it allows using various raw materials (production waste, materials of plant and animal origin), while the obtained products may be applied in various fields of human activity [14, 16].

Bioconversion occurs without high pressure and temperature as a result of enzymatic reactions, therefore

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the process is considered to be the most efficient one, as compared to the known methods of processing raw materials [17]. Besides, technological support of the bioconversion processes is simple [18]. The products obtained by bioconversion are environment friendly, since waste of animal origin is used as raw material. In this regard, the use of bioconversion allows reducing the cost, and accelerating the production process, as well as reducing the cost of protection from soil, water and air contamination [16, 19].

This work is aimed at choosing various equipment configurations in the process lines in order to optimize the process of obtaining biofertilizers from poultry waste.

MATERIALS AND METHODS

The object of research included:

- the poultry waste from LLC "Kuzbass Broiler" (Kemerovo region, Russia): fresh chicken litter; litter from poultry houses; fresh litter from the cages; broiler litter from the nest material.

The obtained biofertilizers were analyzed with the use of the following methods:

The mass fraction of moisture and dry residue in the biofertilizers were determined in accordance with GOST 26713-85 "Organic fertilizers. The method of determining moisture and dry residue content".

The mass fraction of organic matter in the biofertilizers was determined by the oxidimetrically method in accordance with GOST 27980-88 "Organic fertilizers. Methods of determining organic matter content".

The PH value of the biofertilizers was determined in accordance with GOST 27979-88 "Organic fertilizers. pH value determination method".

The mass fraction of total nitrogen in biofertilizers was determined with the use of the Doumas method with RAPID N Cube protein nitrogen analyzer.

Total potassium content in biofertilizers was determined by the weight tetraphenylborate method in accordance with GOST 20851.3-93 "Mineral fertilizers. Methods of determining the mass fraction of potassium".

Total phosphorus content in biofertilizers was determined in accordance with GOST 26717-85 "Organic fertilizers. The method of determining total phosphorus content".

The index of sanitary indicative microorganisms, and **the presence of pathogenic and malignant microorganisms** in the biofertilizers were determined in accordance with GOST 33379-2015 "Organic fertilizers. Methods of determining presence of pathogenic and conditionally pathogenic microorganisms".

The content of arsenic in the samples of biofertilizers was determined in accordance with GOST 26930-86 "Raw materials and food products. The method of determining arsenic".

Content of lead, cadmium and mercury in the studied samples of biofertilizers was determined in accordance with GOST R 53218-2008 "Organic fertilizers. The atomic absorption method for determining the content of heavy metals".

The content of organochlorine pesticides in biofertilizers was determined by gas-liquid chromatography in accordance with GOST 30349-96 "Fruits, vegetables and products of processing them. Methods of determining residual amounts of organochlorine pesticides".

Effective specific activity of natural radionuclides in biofertilizers was determined in accordance with GOST R 53745-2009 "Organic fertilizers. Methods of determining effective specific activity of natural radionuclides".

RESULTS

The flowsheet of poultry waste bioconversion in mechanization is shown in Figure-1.

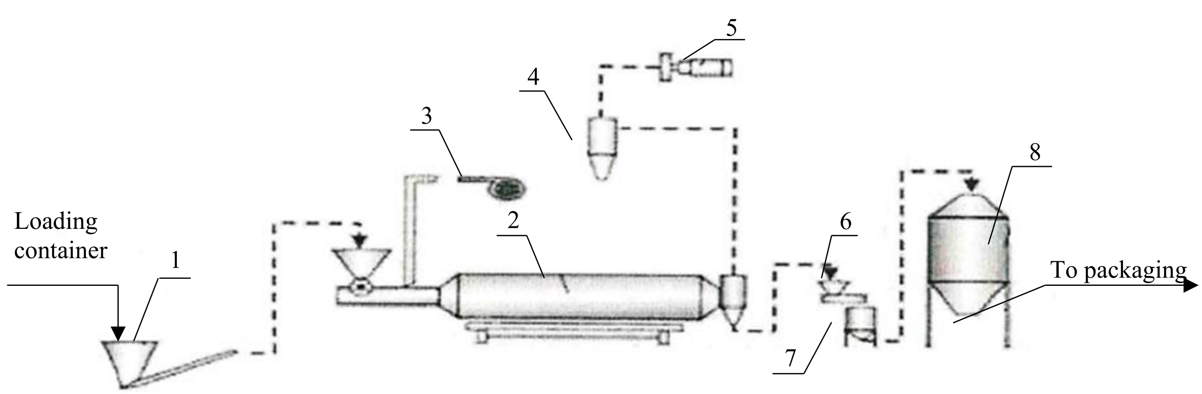

Figure-1. The flowsheet of poultry waste bioconversion in mechanization:
1 - poultry waste conveyor, 2 - disperser, 3 - sterilizer, 4 - nutrient medium mixer, 5 - column for continuous sterilization of the nutrient medium flow, 6 - holder heat exchanger, 7 - seed tanks, 8 - fermentation reactor

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The main element of the line is the universal fermentation reactor that allows bio-degradation poultry waste in the flow.

According to the results of the previous studies, the following parameters have been chosen for the process of bioconversion by a consortium of destructor microorganisms *Bacillus licheniformis* B-2986, *Streptomyces ornatus* S-1220, *Penicillium rubrum* F-601 and *Verticilium lateritium* F-626 (in the ratio of 1:1:1:1): duration of 12.0 hours; temperature of 37°C; pH of 7.5; the ratio of the volume of the seed stock to volume of process material of 1:5.0. In these conditions, the degree of poultry waste bioconversion was 80.6-83.5% [18, 20].

The process of bioconversion in the pilot installation includes several consequent stages.

In the first stage, poultry waste is processed with a weak alkaline solution that has no adverse action on waste, and minced.

Next, protein is transformed into a form that is susceptible to the action of proteolytic enzymes, by treatment with a solution containing 3% NaOH (at room temperature) for 8.0 hours, after which the alkaline hydrolysate is neutralized with a 35-40 % solution of phosphoric acid until reaching pH of 7.5.

In parallel, microorganisms *Bacillus licheniformis* B-2986, *Streptomyces ornatus* S-1220, *Penicillium rubrum* F-601 and *Verticilium lateritium* F-626 (at the ratio of 1:1:1:1) were cultivated at pH 7.5, temperature of 37°C, duration of 12.0 h on a nutrient medium for activating proteolytic enzymes. The composition of the medium for strain cultivation (g/l medium): soluble starch - 15.0; sodium chloride - 5.0; ammonium sulphate - 2.0; calcium carbonate -0.2; sodium nitrate - 1.0; potassium dihydrophosphate - 0.5; manganese chloride - 0.002; magnesium sulfate - 0.5; potassium chloride - 0.5; saccharose - 25.0; agar - 15.0; glucose - 20.0.

Next, the prepared poultry waste is biologically converted by a consortium of destructor microorganisms with chosen parameters.

At the end of the bioconversion, the hydrolysate is inactivated. Inactivation parameters (temperature of 98°C, duration of 10 to 15 min.) are chosen so that the microorganisms stop division, and the enzymes stop affecting the hydrolyzate.

Peculiarities of modernizing the experimental technological line are its components - modern devices and apparatuses that allow simulating a range of variants of the biomass fractionation obtained after bioconversion of poultry waste, the necessity to assess the depth and parameters of separating the biomass into liquid and solid phases, to provide high-quality defatting and bleaching of the product and to prepare the obtained organic product (broth) for subsequent processing (drying), as well as availability of manual and automatic control modes, which allow operators to vary flow rate, rotation speed of the screw in the decanter centrifuge, to control the quality of phase separation and the degree of removing impurities and fat from the broth in the separator.

After installation and commissioning of the upgraded pilot line, various equipment configurations were tested (refiner, decanter and separator) to upgrade the experimental processing line for obtaining biofertilizers from poultry waste and ensuring mechanical cleaning and defatting of the primary broth.

We tested three variants of equipment configuration in the process line for obtaining organic fertilizers from poultry waste, and chose the optimum configuration of equipment that fully meets the process requirements.

Variant No. 1 of equipment configuration:
Fermenter → Pump → Refiner → Receiving tank → Pump → Separator → Pump → Receiving tank.

After bioconversion by a consortium of destructor microorganisms, the fermented mass is pumped from the fermenter to the refiner, which is a coarse effluent filter. At the outlet of the coarse filter, 2 fractions are obtained - "solid" and "liquid" (broth + fat).

The following variables were studied for this process:

- grid cell diameter (0.3 and 0.5 mm);
- blade angle (30, 45, 60 and 75 ^{0});
- feed rate of the fermented mass (1.5; 1.0; 0.5 m^3/h).

The optimum diameter of grid cells was preliminarily chosen, which varied between 0.3 and 0.5 mm. The other two parameters (blade angle, feed rate of the fermented mass) remained constant: blade angle was 30°; feed rate of the fermented mass was 1.0 m^3/h. Bioconversion of the waste was performed with the following parameters: temperature - 37°C; pH - 7.5; duration - 12.0 h

In order to select the optimum cell diameter, the physico-chemical parameters of the obtained biofertilizers were analyzed. The obtained results are shown in Table-1.

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Table-1. Quality indicators of experimental batches of biofertilizer obtained by varying the grid cell diameter.

Indicator name	Indicator value	
	Grid cell diameter 0.3 mm	Grid cell diameter 0.5 mm
Dry substance weight, %	5.6±0.6	5.3±0.5
Mass fraction of organic matter, %	93.8±9.4	86.7±8.7
pH	7.0	7.2±0.7
Mass fraction of total nitrogen, %	10.8±1.1	8.9±0.9
Mass fraction of total potassium, %	9.5±1.0	7.5±0.8
Mass fraction of total phosphorus, %	5.8±0.6	4.5±0.5

The data in Table-1 shows that grid cell diameter equal to 0.3 mm is most favorable, since in this case the biofertilizer is characterized by higher content of organic matter, total nitrogen, total potassium and total phosphorus.

Next, the optimum blade angle was chosen by varying it in the range between 30° and 75° (grid cell diameter was 0.3 mm; fermented mass feed rate was 1.0 m^3/h). The obtained results are shown in Table-2.

Table-2. Quality indicators of experimental batches of the biofertilizers obtained by varying the blade angle.

Indicator name	Indicator value			
	Blade angle 30°	Blade angle 45°	Blade angle 60°	Blade angle 75°
Dry substance weight, %	5.6±0.6	5.5±0.6	5.7±0.6	5.3±0.5
Mass fraction of organic matter, %	93.8±9.4	90.0±9.0	95.6±9.6	88.7±8.9
pH	7.0	6.8	7.0	7.2
Mass fraction of total nitrogen, %	10.8±1.1	9.0±0.9	11.6±1.2	8.4±0.8
Mass fraction of total potassium, %	9.5±1.0	7.5±0.8	10.5±1.1	7.0±0.7
Mass fraction of total phosphorus, %	5.8±0.6	4.0±0.4	6.7±0.7	3.8±0.4

Table-2 shows that the optimum value of blade angle is 60°, since this variant ensures the maximum value of the mass fraction of organic matter, nitrogen, potassium and phosphorus.

Finally, the optimal value of the fermented mass feed rate was chosen by varying it in the range between 0.5 and 1.5 m^3/h (grid cell diameter was 0.3 mm; blade angle was 60°). The obtained results are shown in Table-3.

Table-3. Quality indicators of experimental batches of biofertilizers obtained by varying the rate of feeding fermented mass into the refiner.

Indicator name	Indicator value		
	Feed rate of the fermented mass 0.5 m^3/h	Feed rate of the fermented mass 1.0 m^3/h	Feed rate of the fermented mass 1.5 m^3/h
Dry substance weight, %	5.5±0.6	5.7±0.6	5.6±0.6
Mass fraction of organic matter, %	92.3±9.2	95.6±9.6	96.3±9.6
pH	6.8	7.0	7.0
Mass fraction of total nitrogen, %	10.4±1.0	11.6±1.2	12.6±1.3
Mass fraction of total potassium, %	9.6±1.0	10.5±1.1	11.5±1.2
Mass fraction of total phosphorus, %	6.5±0.7	6.7±0.7	7.8±0.8

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According to the data in Table-3, the optimum value of the fermented mass feed rate is 1.5 m^3/h.

After the coarse effluent filter, the 'liquid' fraction is fed into the receiving tank, and then pumped into the separator for fat separation and broth lightening.

The following variable parameters of separation were studied:

- feed rate of the fermented mass (1.5; 1.2; 0.6 m^3/h).
- duration of drum washing (slurry unloading from the mud space after 5, 15, 30 and 45 minutes).

During the experiment, the rate of feeding the fermented mass into the separator for defatting the broth varied. The physico-chemical characteristics of the obtained fertilizer are shown in Table-4.

Table-4. Quality indicators of experimental batches of biofertilizers obtained by varying the rate of feeding fermented mass into the separator.

Indicator name	Indicator value		
	Feed rate of the fermented mass 0.6 m^3/h	Feed rate of the fermented mass 1.2 m^3/h	Feed rate of the fermented mass 1.5 m^3/h
Dry substance weight, %	5.6±0.6	5.2±0.5	5.1±0.5
Mass fraction of organic matter, %	96.5±9.6	89.4±8.9	85.4±8.5
pH	7.0	7.0	7.0
Mass fraction of total nitrogen, %	13.0±1.3	10.5±1.1	9.8±1.0
Mass fraction of total potassium, %	12.0±1.2	8.0±0.8	7.5±0.8
Mass fraction of total phosphorus, %	8.0±0.8	5.0±0.5	4.5±0.5

Table-4 shows that the maximum impurities removal from the biofertilizers was achieved when the rate of feeding fermented mass into the separator was 0.6 m^3/h.

The optimum duration of drum washing was defined as the time required for timely sludge removal. In this variant of instrument solutions, the sludge (emulsion) was removed from the drum of the separator every 5 minutes.

Variant No. 2 of equipment configuration:
Fermenter → Pump → Decanter → Receiving tank → Pump → Separator → Pump → Receiving tank.
After bioconversion, the fermented mass is pumped from the fermenter into the decanter, i.e. a horizontal centrifuge for separating suspended particles. At the outlet of the centrifuge, 2 fractions are obtained - "solid" and "liquid" (broth + fat).

The following variable parameters of the process were studied:

- feed rate of the fermented mass (0.6 and 0.3 m^3/h).

To select the optimum rate of feeding the fermented mass into the centrifuge, the physico-chemical parameters of the biofertilizer obtained at two rates of feeding the fermented mass into the centrifuge were studied: 0.3 and 0.6 m^3/h. The obtained results are shown in Table-5.

Table-5. Quality indicators of experimental batches of biofertilizers obtained by varying the rate of feeding fermented mass into the centrifuge.

Indicator name	Indicator value	
	Feed rate of the fermented mass 0.3 m^3/h	Feed rate of the fermented mass 0.6 m^3/h
Dry substance weight, %	5.2±0.5	5.6±0.6
Mass fraction of organic matter, %	90.2±9.0	92.2±9.2
pH	7.4	7.4
Mass fraction of total nitrogen, %	10.3±1.0	11.0±1.1
Mass fraction of total potassium, %	8.6±0.9	9.4±0.9
Mass fraction of total phosphorus, %	5.9±0.6	6.3±0.6

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Based on the analysis of the data in Table-5, the optimum rate of feeding fermented mass into the centrifuge is 0.6 m^3/h.

However, the physico-chemical parameters like mass fraction of the organic matter, total nitrogen, potassium and phosphorus, the biofertilizers obtained in this variant of equipment configuration are inferior to those of the biofertilizers obtained in the first variant of the experiment.

Variant No. 3 of equipment configuration:
Fermenter → Pump → Refiner → Receiving tank → Pump → Decanter → Receiving tank → Pump → Separator → Pump → Receiving tank.

After bioconversion, the fermented mass is pumped from the fermenter into the refiner. At the outlet of the refiner, 2 fractions are obtained - "solid" and "liquid" (broth + fat).

After the refiner, the "liquid" fraction is fed into the receiving tank; from the receiving tank it is pumped into the "decanter" centrifuge for additional purification from solid particles.

At the outlet of the decanter, 2 fractions are obtained – "solid" and "liquid" (broth + fat).

The variable parameter of decanter operation was studies, i.e. the feed rate of the fermented mass (0.6; 0.3 m^3 /h).

The results of the experiments for optimizing the rate of feeding the fermented mass into the decanter are shown in Table-6.

Table-6. Quality indicators of experimental batches of biofertilizers obtained by varying the rate of feeding fermented mass into the decanter.

Indicator name	Indicator value	
	Feed rate of the fermented mass 0.3 m^3/h	**Feed rate of the fermented mass 0.6 m^3/h**
Dry substance weight, %	5.0±0.5	5.6±0.6
Mass fraction of organic matter, %	91.1±9.1	88.7±8.9
pH	7.3	7.0
Mass fraction of total nitrogen, %	10.2±1.0	9.8±1.0
Mass fraction of total potassium, %	9.0±0.9	8.5±0.9
Mass fraction of total phosphorus, %	6.0±0.6	5.4±0.5

Based on the analysis of the data in Table-6, the optimum rate of feeding fermented mass into the decanter is 0.6 m^3/h.

After the decanter, the "liquid" fraction is pumped into the receiving tank, and then from the receiving tank into the separator for separating fat and lightening the broth.

Thus, using the pilot processing line, three experimental batches of biofertilizers were obtained from poultry waste (three variants of equipment configuration), the physico-chemical quality indicators of which were analyzed, as well as the chemical and microbiological safety indicators (Table-7).

Table-7. Quality and safety indicators of experimental batches of biofertilizers obtained from poultry waste.

Indicator name	Indicator value		
	Experimental batch No. 1	Experimental batch No. 2	Experimental batch No. 3
Dry substance weight, %	5.6±0.6	5.6±0.6	5.0±0.5
Mass fraction of organic matter, %	96.5±9.6	92.2±9.2	91.1±9.1
pH	7.0	7.4	7.3
Mass fraction of total nitrogen, %	13.0±1.3	11.0±1.1	10.2±1.0
Mass fraction of total potassium, %	12.0±1.2	9.4±0.9	9.0±0.9
Mass fraction of total phosphorus, %	8.0±0.8	6.3±0.6	6.0±0.6
The index of sanitary-indicative microorganisms, cells/g coliforms enterobacteria	2 1	2 2	1 Not found
Presence of pathogenic and malignant microorganisms, cells/g, including enterobacteria, enterococci, enteroviruses	Not found	Not found	Not found
Mass concentration of lead, mg/kg of dry matter	8.5±0.9	10.0±1.0	5.5±0.6
Mass concentration of cadmium, mg/kg of dry matter	0.050±0.005	Not found	Not found
Mass concentration of arsenic, mg/kg of dry matter	0.54±0.05	0.22±0.02	Not found
Mass concentration of mercury, mg/kg of dry matter	Not found	Not found	Not found
Mass concentration of pesticides residues in the dry matter, mg/kg of dry matter: hexachlorocyclohexane (sum of isomers) dichlordiphenyl trichlormethyl methane and its metabolites (cumulative quantity)	Not found 0.005±0.0005	Not found Not found	Not found Not found
Effective specific activity of natural radionuclides, Bq/kg of dry matter	15±2	10±1	10±1

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DISCUSSIONS

The presented data testify that all experimental batches of biofertilizers, which were obtained from poultry waste as a result of various equipment configurations in the production line, feature high organic matter content (91.1-96.5% in the terms of dry substance), nitrogen (10.2-13.1% in the terms of dry substance), potassium (9.0-12.0% in the terms of dry matter) and phosphorus (6.0-8.0% in the terms of dry substance). By the chemical, microbiological and safety parameters, the biofertilizers obtained from poultry waste meet the requirements of the current normative documentation.

CONCLUSIONS

Based on the said above, it's possible to conclude that all the three tested equipment configurations in the pilot line result in obtaining biofertilizers from poultry waste, which meet the requirements of the current normative documents, and can be used to develop a processing line for obtaining biofertilizers based on the product of bioconversion of poultry waste.

Based on the results of analyzing the physico-chemical, microbiological and veterinary and sanitary indicators of the prototypes of biofertilizers obtained from poultry waste, it has been found that the highest physico-chemical parameters (mass fraction of organic matter, nitrogen, potassium and phosphorus) are characteristic of the biofertilizers obtained with equipment configuration No. 1.

This line is unique, and has no analogues in Russia and in the world, both in terms of its configuration, and the functional purpose of its individual elements. The main components of the line are the modern world-class elements and devices allowing simulating and studying the process of raw material dehydration and preparation before feeding it into the universal fermentation reactor.

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