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Selection of Modes of Poultry Waste Conversion into Biofertilizers

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Abstract

This article describes bioconversion of poultry waste on pilot production line at optimum process variables: 37°C; pH 7.5; 12.0 h. Process sites of the pilot line for production of biofertilizers from poultry waste have been optimized: three experimental batches of biofertilizers have been obtained during implementation of three different arrangements. It is established that all three tested equipment layouts in the pilot production line produce biofertilizers from poultry waste meeting the requirements of existing regulatory documents. Optimum modes of bioconversion of poultry waste on the pilot production line have been selected.

Key words: poultry waste, bioconversion, decomposers, pilot production line, process variables, production process.

INTRODUCTION

Production of complete biofertilizer (BF) is closely related with reasonable and efficient consumption of its resources with accounting for existing conversion facilities and properties of poultry waste [1, 2].

Domestic livestock breeding is obviously the main source of biological fertilizers intended for agriculture of advanced economies [3, 4].

Not to take anything away from production waste of beef, pork, lamb, milk, and fish, peculiar attention is paid to poultry waste in production of BF of animal origin [5].

Contribution of poultry industry into production of meat in Russia is 1.2 million t per year. This is accompanied by formation of 0.4 million t of poultry waste, thus creating significant problem for processing industry and requires for solution of the following issues [6]:

- provision of biological safety;
- provision of environmental safety;
- production of health valuable products (proteins, fat, biologically active products, etc.);
- production of feed additives for cattle;
- production of energy;
- production of BF.

Production of biofertilizers is an urgent issue of modern agro-industrial sector [7].

This work is aimed at bioconversion of poultry waste at pilot production line in order to validate the modes of bioconversion, selection of optimum modes of bioconversion of poultry waste and optimization of equipment arrangement in order to produce biofertilizers.

Poultry waste was converted at pilot production line, the main target was optimization of equipment arrangement for production of biofertilizers.

The components of pilot production line are modernized: advanced instrumentation and devices allowing to simulate various configurations of fractionation of biomass obtained after conversion of poultry waste, to estimate the depth and separation variables of this biomass into liquid and solid phases, to provide sufficient defatting and clarification of the product and to prepare the obtained organic product (broth) for subsequent processing (drying); in addition manual and automatic control modes are available thus enabling variations of flow rate, screw rotation speed in decanter centrifuge, control of phase separation quality and degree of broth purification from impurities and fat in separator [8, 9, 10].

METHODS

The subject matters of the experiments were as follows: poultry waste from OOO Kuzbass Broiler (Kemerovo oblast, Russia): fresh chicken manure; manure removed from poultry yards; fresh cage manure; broiler nesting manure.

Poultry waste was bioconverted using consortium of decomposers: *Bacillus licheniformis* B-2986, *Streptomyces ornatus* S-1220, *Penicillium rubrum* F-601 and *Verticilium lateritium* F-626.

The output of pilot production line for poultry waste bioconversion is at least 300 kg/h; it is comprised of conveyor for poultry waste, disperser, sterilizer, mixer of nutrition medium, column for continuous sterilization of nutrient medium flow, heat exchanger/holder, inoculants, experimental fermentation reactor.

This is a unique line, it has no analogues in Russia and abroad both in terms of its arrangement and with regard to functional purpose of separate components. The main components of the line are advanced tools and apparatuses making it possible to simulate and to study dewatering and preparation of raw materials before supply to universal fermentation reactor.

The universal fermentation reactor is the major element of the production line, it performs in-line biodestruction of poultry waste. Using this line, it is possible to test various modes of poultry waste conversion with obtaining of highly efficient biofertilizers with dry solids content of at least 98.0 wt % and organics content of at least 90.0 wt %.

The designed manual and automatic control modes make it possible to vary the raw flow rate at each process component, holding time of the converted raw material in processing equipment. The obtained results make it possible to make appropriate adjustments directly to the developed bioconversion of poultry waste. This can be applied to moisture content of raw material, temperature and duration of the biodestruction.

Testing of optimum process mode of poultry waste bioconversion using the production line eliminates the risks of scaling up the production of biofertilizers on commercial scale.

Specifications of equipment for bioconversion of poultry manure into biofertilizers are summarized in Table 1.

RESULTS AND DISCUSSION

It is established that the optimum variables of poultry waste bioconversion are as follows:

- temperature: 37°C;
- pH 7.5;
- duration: 12.0 h.

This research stage was devoted to experiments of poultry waste bioconversion at pilot production line, the main target was to optimize arrangement of process sites for production of biofertilizers.

The components of pilot production line are modernized: advanced instrumentation and devices allowing to simulate various configurations of fractionation of biomass obtained after conversion of poultry waste, to estimate the depth and separation variables of this biomass into liquid and solid phases, to provide sufficient defatting and clarification of the product and to prepare the obtained organic product (broth) for subsequent processing (drying); in addition manual and automatic control modes are available thus enabling variations of flow rate, screw rotation speed in decanter centrifuge, control of phase separation quality and degree of broth purification from impurities and fat in separator [8, 9, 10].

Table 1 – Specifications of equipment for bioconversion of poultry manure into biofertilizers

Item	Description	Amount
1	Conveyor for poultry manure removal	1
2	Disperser	1
3	Sterilizer	1
4	Mixer of nutrition medium	1
5	Column for continuous sterilization of nutrient medium flow	1
6	Heat exchanger/holder	1
7	Inoculants	2
8	Experimental fermentation reactor	1

Table 2 – Quality indices of test batches of biofertilizers obtained with varied mesh sizes

Property	Value	
	Mesh size: 0.3 mm	Mesh size: 0.5 mm
Dry matters, %	5.6	5.3
Organics, %	93.8	86.7
Ph	7.0	7.2
Total nitrogen, %	10.8	8.9
Total potassium, %	9.5	7.5
Total phosphorus, %	5.8	4.5

Table 3 – Quality indices of test batches of biofertilizers obtained with varied blade angles

Property	Value			
	Blade angle: 30°	Blade angle: 45°	Blade angle: 60°	Blade angle: 75°
Dry matters, %	5.6	5.5	5.7	5.3
Organics, %	93.8	90.0	95.6	88.7
pH	7.0	6.8	7.0	7.2
Total nitrogen, %	10.8	9.0	11.6	8.4
Total potassium, %	9.5	7.5	10.5	7.0
Total phosphorus, %	5.8	4.0	6.7	3.8

Table 4 – Quality indices of test batches of biofertilizers obtained with varied feed rate of fermented bulk into refiner

Property	Value		
	Feed rate: 0.5 m^3/h	Feed rate: 1.0 m^3/h	Feed rate: 1.5 m^3/h
Dry matters, %	5.5	5.7	5.6
Organics, %	92.3	95.6	96.3
pH	6.8	7.0	7.0
Total nitrogen, %	10.4	11.6	12.6
Total potassium, %	9.6	10.5	11.5
Total phosphorus, %	6.5	6.7	7.8

Table 5 – Quality indices of test batches of biofertilizers obtained with varied feed rate of fermented bulk into separator

Property	Value		
	Feed rate: 0.6 m^3/h	Feed rate: 1.2 m^3/h	Feed rate: 1.5 m^3/h
Dry matters, %	5.6	5.2	5.1
Organics, %	96.5	89.4	85.4
pH	7.0	7.0	7.0
Total nitrogen, %	13.0	10.5	9.8
Total potassium, %	12.0	8.0	7.5
Total phosphorus, %	8.0	5.0	4.5

Table 6 – Quality indices of test batches of biofertilizers obtained with varied feed rate of fermented bulk into centrifuge

Property	Value	
	Feed rate: 0.3 m^3/h	Feed rate: 0.6 m^3/h
Dry matters, %	5.2	5.6
Organics, %	90.2	92.2
pH	7.4	7.4
Total nitrogen, %	10.3	11.0
Total potassium, %	8.6	9.4
Total phosphorus, %	5.9	6.3

Table 7 – Quality indices of test batches of biofertilizers obtained with varied feed rate of fermented bulk into decanter

Property	Value	
	Feed rate: 0.3 m^3/h	Feed rate: 0.6 m^3/h
Dry matters, %	5.0	5.6
Organics, %	91.1	88.7
pH	7.3	7.0
Total nitrogen, %	10.2	9.8
Total potassium, %	9.0	8.5
Total phosphorus, %	6.0	5.4

After assembling and commissioning of the modernized pilot production line, various equipment arrangements were tested (refiner, decanter and separator) aimed at modernization of experimental line for production of biofertilizers from poultry waste and provision of mechanical cleaning and defatting of primary broth [11]. Three arrangements of this equipment of the line for production of biofertilizers from poultry waste were tested, the most optimum arrangement was selected totally meeting the process requirements.

- Arrangement No. 1: Fermenter → Pump → Refiner → Receiving tank → Pump → Separator → Pump → Receiving tank.
- Arrangement No. 2: Fermenter → Pump → Decanter → Receiving tank → Pump → Separator → Pump → Receiving tank.
- Arrangement No. 3: Fermenter → Pump → Refiner → Receiving tank → Pump → Decanter → Receiving tank → Pump → Separator → Pump → Receiving tank.

Arrangement No. 1

Fermented bulk after bioconversion by the decomposer consortium was supplied from the fermenter by the pump to the refiner – effluent filter of coarse cleaning. Two fractions were obtained at output of the coarse filter: solid and liquid (broth + fat).

The following process variables were analyzed:

– mesh size (0.3 and 0.5 mm);
– blade angle (30, 45, 60 and 75°);
– feed rate of fermented bulk (1.5; 1.0; 0.5 m^3/h).

Table 8 – Indices of quality and safety of test batches of biofertilizers from poultry waste

Property	Value		
	Test batch No.1	Test batch No.2	Test batch No.3
Dry matters, %	5.6	5.6	5.0
Organics, %	96.5	92.2	91.1
pH	7.0	7.4	7.3
Total nitrogen, %	13.0	11.0	10.2
Total potassium, %	12.0	9.4	9.0
Total phosphorus, %	8.0	6.3	6.0
Sanitary indicator microorganisms, cells/g coliforms enterobacteria	2 1	2 2	1 Not detected
Pathogenic microorganisms, cells/g, including enterobacteria, enterococcus, enteroviruses	Not detected	Not detected	Not detected
Lead weight content, mg/kg on dry basis	8.5	10.0	5.5
Cadmium weight content, mg/kg on dry basis	0.050	Not detected	Not detected
Arsenic weight content, mg/kg on dry basis	0.54	0.22	Not detected
Mercury weight content, mg/kg on dry basis	Not detected	Not detected	Not detected
Weight content of residual pesticides,mg/ kg on dry basis: hexachlorocyclohexane (sum of isomers) dichlorodiphenyltrichloroethane and its metabolites (cumulative)	 Not detected 0.0005	 Not detected Not detected	 Not detected Not detected
Effective specific activity of natural radionuclides, Bq/kg on dry basis	15	10	10

a) numerator: without conversion to dry basis; denominator: on dry basis

Optimum mesh size was selected preliminary which then was varied in the range from 0.3 to 0.5 mm. At this, two other variables (blade angle, fermented bulk feed rate) were constant: blade angle of 30°, fermented bulk feed rate of 1.0 m^3/h. Bioconversion of poultry waste at pilot production line was carried out at 37°C; pH 7.5; 12.0 h.

Aiming at selection of optimum mesh size the physicochemical properties of the obtained biofertilizers were analyzed. The acquired results are summarized in Table 2.

The data in Table 2 evidence that the mesh size of 0.3 mm is the most preferable, in this case the biofertilizers are characterized by the highest content of organics, total nitrogen, total potassium, and total phosphorus in comparison with those obtained with mesh size of 0.5 mm.

Then, the optimum blade angle was selected in the range from 30 to 75° (mesh size: 0.3 mm; fermented bulk feed rate: 1.0 m^3/h). The obtained results are summarized in Table 3.

It follows from Table 3 that the optimum blade angle is 60°, in this case maximum weight contents of organics, nitrogen, potassium, and phosphorous are obtained.

Finally, the optimum feed rate of fermented bulk was selected in the range from 0.5 to 1.5 m^3/h (mesh size: 0.3 mm; blade angle: 60°). The obtained results are summarized in Table 4.

According to Table 4 the optimum fermented bulk feed rate is 1.5 m^3/h.

After the effluent filter of coarse cleaning the liquid fraction is supplied to the receiving tank, and then by the pump to the separator to separate fat and to clarify broth.

The following separation variables were analyzed:

- fermented bulk feed rate (1.5; 1.2; 0.6 m^3/h);
- drum washing duration (mud discharge from processing space in 5, 15, 30 and 45 min).

During the experiment the fermented bulk feed rate to separator for broth defatting was varied. Physicochemical properties of the obtained biofertilizers are summarized in Table 5.

It follows from Table 5 that the maximum level of cleaning of biofertilizers from impurities is achieved at the fermented bulk feed rate to separator of 0.6 m^3/h.

Selection of optimum duration of drum washing was determined as the time required for on-time mud removal. With this equipment arrangement the mud (emulsion) from separator drum was removed each 5 min which was insufficient for the procedure.

Therefore, the following variables were selected for bioconversion of poultry waste and subsequent cleaning of biofertilizers at pilot production line comprised of Fermenter → Pump → Refiner → Receiving tank → Pump → Separator → Pump → Receiving tank: 37°C; pH 7.5; 12.0 h; mesh size: 0.3 mm; blade angle: 60°; fermented bulk feed rate to refiner: 1.5 m^3/h; fermented bulk feed rate to separator for broth clarification: 0.6 m^3/h.

Arrangement No. 2

Fermented bulk after bioconversion was supplied from the fermenter by the pump to the decanter – horizontal centrifuge for separation of suspended particles. Two fractions were obtained at the centrifuge output: solid and liquid (broth + fat).

The following variables were analyzed:

- fermented bulk feed rate to centrifuge (0.6 and 0.3 m^3/h).

In order to select optimum fermented bulk feed rate to centrifuge, the physicochemical properties of biofertilizers were analyzed obtained at two feed rates: 0.3 and 0.6 m^3/h. The obtained results were summarized in Table 6.

Based on the results in Table 6, the optimum fermented bulk feed rate to centrifuge was selected: 0.6 m^3/h.

In terms of such physicochemical properties as weight content of organics, total nitrogen, potassium, and phosphorus, the biofertilizers obtained with such equipment arrangement are inferior than those with the first arrangement.

Therefore, the following variables were selected for poultry waste bioconversion and subsequent cleaning of biofertilizers at pilot production line comprised of Fermenter → Pump → Decanter → Receiving tank → Pump → Separator → Pump → Receiving tank: 37°C; pH 7.5; 12.0 h; fermented bulk feed rate to centrifuge: 0.6 m^3/h.

Arrangement No. 3

Fermented bulk after bioconversion was supplied from the fermenter by the pump to the refiner. Two fractions were obtained at the refiner output: solid and liquid (broth + fat).

After the refiner the liquid fraction was supplied to the receiving tank; and from the receiving tank by the pump to the decanter for additional cleaning from solid particles.

Two fractions were obtained at the decanter output: solid and liquid (broth + fat).

The following decanter variable was analyzed: fermented bulk feed rate (0.6; 0.3 m^3/h).

The experimental results on optimization of fermented bulk feed rate to decanter are summarized in Table 7.

Based on the data in Table 7, the optimum fermented bulk feed rate to decanter was selected: 0.3 m^3/h.

After the decanter the liquid fraction was supplied to the receiving tank and from the receiving tank by the pump to the separator in order to separate fat and to clarify broth. Based on the obtained results on equipment tested, the arrangement and operation modes of process sites for broth cleaning and clarification were optimized.

Therefore, the variables were selected for bioconversion of poultry waste and subsequent cleaning of biofertilizers at pilot production line comprised of Fermenter → Pump → Refiner → Receiving tank → Pump → Decanter → Receiving tank → Pump → Separator → Pump → Receiving tank: 37°C; pH 7.5; 12.0 h; fermented bulk feed rate to decanter: 0.3 m^3/h.

Three test batches of biofertilizers from poultry were obtained at the pilot production line (three equipment arrangements) [12], physicochemical properties as well as chemical and microbiological safety indices were analyzed for these batches (Table 8).

The data in Table 8 evidence that all test batches of biofertilizers from poultry waste are characterized by high content of organics (91.1-96.5% on dry basis), nitrogen (10.2-13.1% on dry basis), potassium (9.0-12.0% on dry basis) and phosphorus (6.0-8.0% on dry basis). Chemical and microbiological safety properties of biofertilizers from poultry waste meet the requirements of valid regulatory documentation [13].

CONCLUSION

It can be concluded that all three tested equipment arrangements in the pilot production line improve the biofertilizers from poultry waste meeting the requirements of valid regulatory documentation, they can be applied for development of commercial production line of bioconversion of poultry manure into biofertilizers.

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