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Variation in the mass and moisture content of solid organic waste originating from a pig complex during its fermentation

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Abstract. The focus of the study was the fermentation of an organic waste mixture originating from a pig-rearing complex. The organic waste was processed in the laboratory-scale drum fermenter. Through the fermentation process, the fermented material was weighed by a system of four strain gauges installed under the fermenter. In our previous study, the following initial mixture characteristics were justified to have the fermentation process going – 65% to 70% moisture content and 400–600 kg m^{-3} density. The optimal operation mode of the fermenter was identified depending on the initial mixture composition – aeration frequency of 5 min h^{-1}; air consumption of 11.3 m^3 h^{-1} per 1.7 m^3 of the fermenter volume; drum rotation interval – three times every 12 hours. Under this operating mode, the mass loss was 3% already on the third fermentation day and 7% – on the fifth day. As a result, the mass of the finished organic fertiliser was 9% smaller than that of the loaded mixture. The moisture content of the processed material also decreased: under the average moisture content of the loaded mixture of 68.7%, the average moisture content of the organic fertiliser was 66.4%. Based on the resulting experimental data, the mathematical models describing the dependence of the mass and moisture content of the processed material on the fermentation time were created. The study outcomes allow concluding that the solid-state aerobic fermentation is one of the promising options for the utilisation of the solid fraction of pig slurry.

Key words: organic waste, slurry, organic fertiliser, fermentation, mass, moisture content.

INTRODUCTION

Intensification of pig farming and the herd expansion lead to an increase in the mass of pig slurry produced. The properly processed pig slurry must comply with the State Standard GOST R 53117-2008 'Organic fertilisers based on animal waste: Specifications'. In this case, it can be applied to the fields as an organic fertiliser to improve the soil fertility.

The most common pig slurry processing technology in the North-West of Russia is its solid-liquid separation followed by the passive composting of the solid fraction in clamps and the long-term storing (maturing) of the liquid fraction (Briukhanov & Uvarov, 2015).

Composting is an aerobic process that provides the comfort conditions for the activity of mesophilic and thermophilic microorganisms (Rodhe & Jonsson, 1999). Passive composting has to meet several mandatory requirements for the guaranteed processing of organic components. All parts of the clamp should gain the temperature of at least +50 °C within 10 days after the clamp formation (Uvarov et al., 2019). The processing should last for at least 2 months in the warm season and at least 3 months – in the cold season.

Considering a large number of uncontrollable external factors, such as precipitation, low ambient temperature, etc., the passive composting cannot ensure the high quality of the resulting organic fertiliser. The closed fermenters, free from the outside influences, can significantly improve the quality of the final product and reduce the processing time to several days (Aboltins et al., 2019).

Fermenters with a working body in the form of a horizontal rotating drum provide the mixing and additional aeration of the processed material, thereby avoiding its compaction and the oxygen-deficient pockets in some parts inside the fermenter. This guarantees the stable processing modes and the uniform compost maturation.

An additional advantage of drum fermenters is the higher dry matter content in the final product (Afanassiev et al., 2000) and, consequently, the higher nutrients concentration compared to the fertiliser produced by the passive composting (Poulsen et al., 2006; Sindhöj et al., 2013). The dry matter content of about 30%–50% in the organic fertiliser produced by the fermentation allows to granulate it without additional processing costs, thereby significantly increasing its rational transportation distance.

A pig-rearing complex is a large man-made facility with a significant environmental impact (Priekulis et al., 2019). Along with the basic pig production, the complex also generates different waste: solid household waste, sewage, slury, fodder waste, etc. Each waste is usually processed separately in compliance with its physical and chemical composition and regulated utilisation practices. There are technologies, however, which allow processing a mixture of several wastes, thereby increasing the processing efficiency and reducing the utilisation costs (Shalavina et al., 2017; Dąbrowska et al., 2019). One such technology is the aerobic solid-state fermentation.

The previous studies demonstrated that the recommended physical and chemical characteristics of the mixture, namely 65%–70% moisture content, 400–600 kg m^{-3} density, and C/N ratio of (15–30)/1, ensured the highly intensive fermentation process, complete processing and guaranteed disinfection of the mixture (Shalavina et al., 2019).

The objective of further research was to study the effect of fermentation temperature on the mass and some physical parameters of the fermented mixture.

MATERIALS AND METHODS

A pig-rearing complex located in the North-West Federal District was selected as a pilot farm. It produced two types of the solid fraction of pig slurry: the solid fraction coming from the screw separator and the solid fraction coming from the decanter centrifuge. In addition, the complex generated the waste from the mechanical cleaning of grain. The fermented mixture consisted of these three types of waste (Fig. 1).

The combination of the components was justified in our exploratory research: the solid fraction of pig slurry coming from the screw separator – 60%; the solid fraction of pig slurry coming from the decanter centrifuge – 32%; grain mechanical cleaning waste – 8% (Shalavina et al., 2019). Depending on the specific composition of the mixture to be fermented, the variation pattern of the mass and moisture content of the processed material is different.

Physical and chemical properties of the fermented mixture are shown in Table 1.

Experiments were conducted at IEEP – branch of FSAC VIM from February to June 2019 following the approved programme and methodology on a laboratory-scale drum fermenter (Fig. 2).

Table 1. Physical and chemical properties of the starting components

Indicator	Unit	Value
The solid fraction of pig slurry coming from the screw separator		
Moisture content	%	68.2
pH	-	8.5
Ash content	%	7
N_{total}	mg kg^{-1}	5,600
P_{total}	mg kg^{-1}	2,070
The solid fraction of pig slurry coming from the decanter centrifuge		
Moisture content	%	70.5
pH	-	9.9
Ash content	%	36.4
N_{total}	mg kg^{-1}	8,206
P_{total}	mg kg^{-1}	6,206
Grain mechanical cleaning waste		
Moisture content	%	13.9
pH	-	6.9
Ash content	%	12.5
N_{total}	mg kg^{-1}	1,036
P_{total}	mg kg^{-1}	3,300

Figure 1. The components of the fermented mixture: 1 – the solid fraction of pig slurry coming from the screw separator; 2 – the solid fraction of pig slurry coming from the decanter centrifuge; 3 – grain mechanical cleaning waste.

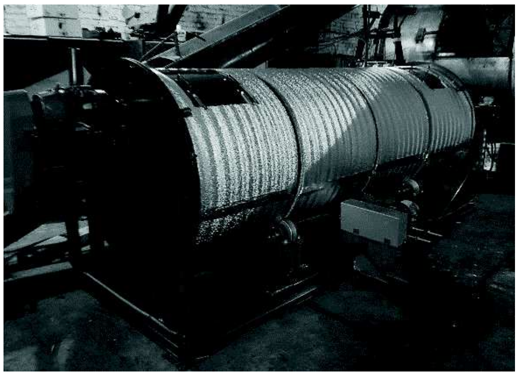

Figure 2. Laboratory-scale drum fermenter.

At the first stage, the initial components were mixed in the justified proportions. The average mass of the loaded mixture was 1,287 kg. The average moisture content of the mixture was 68.7%.

The mass of the processed material was measured by a weighing system of four strain gauges installed under the fermenter. The temperature was measured at six points: two measuring points per the loading, central and unloading parts of the fermenter. The speed and humidity of the supplied air were measured at the aeration air duct inlet using TKA-PKM/60 heat loss anemometer and humidity sensor. The measuring points of the required parameters are shown in Fig. 3.

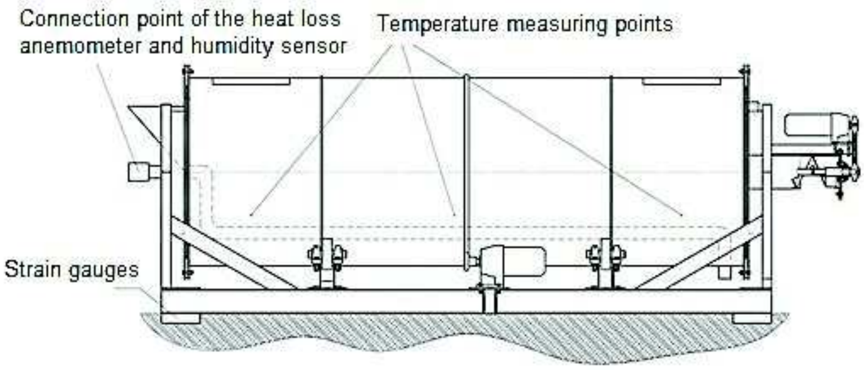

Figure 3. Scheme of the measuring points of the required parameters on the laboratory-scale fermenter.

The moisture content in the selected samples was determined in the laboratory of analytical methods of environmental engineering of IEEP – branch of FSAC VIM following the State Standard GOST 26713-85 'Organic fertilizers: Method for determination of moisture and dry residue'.

After the mixture loading and the mass measurement, the artificial aeration of the fermented mixture was launched. The optimal operation mode of the fermenter was identified in our previous studies depending on the initial composition of the mixture: aeration frequency of 5 min h^{-1}, air consumption of 11.3 m^3 h^{-1} per 1.7 m^3 of the fermenter volume; drum rotation interval – three times every 12 hours.

The fermentation, i.e. processing the mixture into an organic fertiliser, lasted for seven days. The ready organic fertiliser was unloaded on the 7th day after the sampling and the mass measurement was finished.

The processed mixture mass was measured and the samples to determine the moisture content were taken every day at 9:00 A.M.

The experiment had three replications (Valge et al., 2015). The experimental data were processed in *Microsoft Excel* and *Statgraphics Centurion* programmes. The error in the mean values was estimated by Student's t-test. The true value of the mathematical expectation with probability P was in the range

$$P\left[\bar{x} \pm t_V \cdot \frac{\sigma}{\sqrt{n}}\right] = 1 - \alpha \tag{1}$$

where $\bar{x}$ – mean value; t_V – the tabular value for Student's t (for 0.9 probability level the value was 2.92); $1 - a$ – pre-chosen probability (for the fermentation process the value was 0.9); n – number of array elements (in this experiment n = 3); σ – mean-square deviation.

RESULTS AND DISCUSSION

The experiment started on 28 February 2019. The dynamic pattern of the changes in the fermentation temperature of the mixture averaged over the three replications under the specified operating mode is shown in Fig. 4.

A rapid temperature increase was observed: the temperature of the mixture reached +22.8 °C within 24 hours after the experiment started. After 48 hours it increased to +48.5 °C, and after 65 hours a threshold of +55 °C was reached and the temperature never dropped below this value.

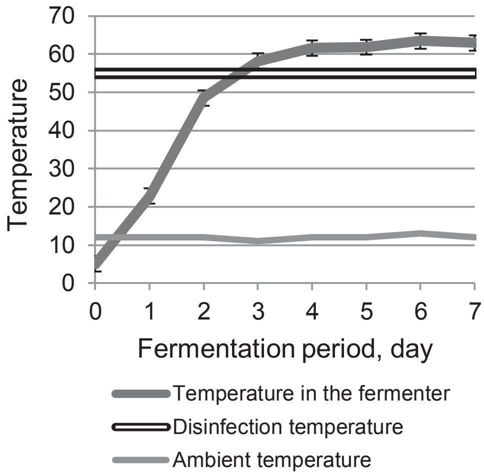

Figure 4. Dynamic pattern of the temperature variation.

The obtained experimental data on the processed mixture mass and the results of their statistical parameters are presented in Table 2

The calculation results showed that the average values fell in the range of standard deviations, therefore, the data were reliable and no suspect data were available.

Table 2. The data on the processed mixture mass in the drum-type fermenter

Fermentation stage	Average mass $\bar{x}$, kg	Dispersion, *D*	$\bar{x}+\sigma$	$\bar{x}-\sigma$	Upper interval limit, *P1*	Lower interval limit, *P2*
Mixture loading into the fermenter	1,287	0	1,287	1,287	1,287	1,287
Fermentation, day 1	1,277.7	30.8	1,283.3	1,272.1	1,287.2	1,268.2
Fermentation, day 2	1,269.3	21.5	1,273.9	1,264.7	1,277.1	1,261.5
Fermentation, day 3	1,248.7	6.8	1,251.3	1,246.1	1,253.1	1,244.3
Fermentation, day 4	1,214	20.6	1,218.5	1,209.5	1,221.6	1,206.4
Fermentation, day 5	1,195	16.6	1,199.1	1,190.9	1,201.9	1,188.1
Fermentation, day 6	1,184.7	50.8	1,191.8	1,177.6	1,196.7	1,172.7
Fermentation, day 7, unloading	1,176.3	42.8	1,182.8	1,169.8	1,187.3	1,165.3

The dependence of the average mixture mass on the fermentation time is shown in Fig. 5.

The graph of average values was found within the error range, verifying their reliability. The correlation coefficient was 0.98.

The mathematical dependence of the processed mixture mass on the fermentation time was described by the following regression expression:

$$M_m = 1{,}293.9 - t \cdot 17.83 \quad (2)$$

where M_m – the processed mixture mass, kg; t – fermentation time, day.

As seen from Fig. 5, the average mass of the loaded mixture was 1,287 kg. Under the specified operating mode, the mass loss was 3% already on the third fermentation day and 7% – on the fifth fermentation day. As a result, the mass of the ready loose organic fertiliser was 9% smaller than the loaded mixture mass and amounted to 1,176.3 kg.

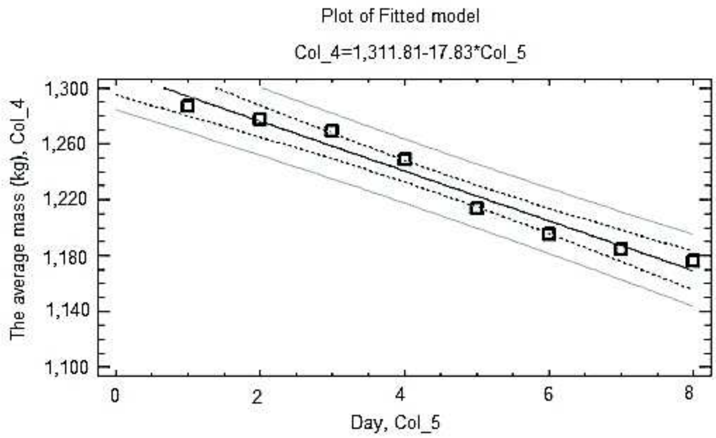

Figure 5. Dependence of the processed mixture mass on the fermentation time.

The obtained experimental data on the moisture content of the processed mixture and the results of their statistical analysis are presented in Table 3.

The results showed that the average values fell in the range of standard deviations, therefore, the data were reliable and no suspect data were available.

According to the study results, the mass of the processed mixture decreased due to changes in the moisture content.

Table 3. Moisture content data of the mixture processed

Fermentation stage	Average moisture content $\bar{x}$, %	Dispersion, *D*	$\bar{x}+\sigma$	$\bar{x}-\sigma$	Upper interval limit, *P1*	Lower interval limit, *P2*
Mixture loading into the fermenter	68.7	0.1	69.01	68.39	69.2	68.2
Fermentation, day 1	68.7	0.25	69.2	68.2	69.5	67.9
Fermentation, day 2	67	0.05	67.2	66.78	67.4	66.6
Fermentation, day 3	66.7	0.02	66.8	66.57	66.9	66.5
Fermentation, day 4	66.9	0.02	67.03	66.77	67.1	66.7
Fermentation, day 5	67.1	0.002	67.15	67.06	67.2	67
Fermentation, day 6	67	0.002	67.05	66.96	67.1	66.9
Fermentation, day 7, unloading	66.4	0.01	66.49	66.31	66.6	66.2

The mathematical dependence of the processed mixture moisture content on the fermentation time was described by the following expression:

$$MC = \sqrt{\left(4{,}394.4 + \frac{297.9}{t}\right)} \qquad (3)$$

where MC – moisture content of the processed mixture, %; t – fermentation time, day.

Moisture content (MC) was calculated from the experimental data in Table 4 by the least square method.

The specific capital and operating costs associated with the fermentation of the organic waste mixture originating from the pig-rearing complex were calculated. The calculations did not consider the construction and maintenance costs of the buildings and sites for the storage of starting components and ready products. The data obtained were compared with the indicators of the traditional processing technology – the passive composting on a concrete pad.

Specific capital costs of fermentation were 3,220 roubles t^{-1} (46 Euros t^{-1}), those of the passive composting – 1,500 roubles t^{-1} (21.4 Euros t^{-1}); specific operating costs of fermentation were 800 roubles t^{-1} (11.4 Euros t^{-1}), those of the passive composting – 355 roubles t^{-1} (5.1 Euros t^{-1}).

The organic waste fermentation in a drum-type installation has several advantages over the traditional passive composting:

– shorter time required – seven days of fermentation against up to three months of passive composting;

– fermentation guarantees the production of organic fertilisers with a specified quality irrespective of the uncontrollable external factors;

– smaller storages are required as the ready organic fertiliser can be immediately sold or stored on the field-edge sites before application.

CONCLUSIONS

The utilisation technology of the farm organic waste in a special installation, a drum-type fermenter, was tested. The microbiological transformation of waste in the aerobic process has important advantages over the composting – lower mass loss, significantly improved quality of the ready organic fertiliser and shorter processing period.

The optimal operation mode of the fermenter was identified in our previous studies depending on the initial composition of the mixture: aeration frequency of 5 min h^{-1}; air consumption of 11.3 $m^3 h^{-1}$ per 1.7 m^3 of the fermenter volume; drum rotation interval – three times every 12 hours.

When the temperature in the fermentation unit exceeded +55 °C, the required time for the bio-thermic treatment was three days. The further processing of the mixture in the fermentation unit allowed to reduce the mass and moisture content of the ready organic fertiliser with the higher nutrient content.

Under the specified operating mode, the mass loss was 3% already on the third fermentation day and 7% – on the fifth fermentation day. As a result, the mass of the ready loose organic fertiliser was 9% smaller than the mass of the loaded mixture.

The experimental data was used to create the mathematical models showing the dependence of the mass and moisture content of the processed raw material on the fermentation time. The models allow forecasting the processing of the organic waste from the pig farms into an organic fertiliser. The study outcomes allow concluding that the solid-state aerobic fermentation is one of the promising options for the utilization of the solid fraction of pig slurry.

REFERENCES

Aboltins, A., Melece, L. & Priekulis, J. 2019. Model for ammonia emissions' assessment and comparison of various dairy cattle farming systems and technologies. *Agronomy Research* **17**(2), 322–332. https://doi.org/10.15159/AR.19.081

Afanassiev, A., Afanassiev, V. & Kaliuga, V. 2000. Energy-saving technology of litter housing of pigs and two-step biofermentation of manure on pig farms. In: *Problemy intensyfikacji produkcji zwierzęcej z uwzględnieniem ochrony środowiska i przepisów UE. VI Międzynarodową Konferencja Naukowa*, Warszawa, Poland, pp. 421–427 (in English).
Briukhanov, A. & Uvarov, R. 2015. Advanced technologies of biofermentation manure / litter for North-West Russia. *Naucnoe obozrenie* **16**, 26–31 (in Russian).
Dąbrowska, M., Świętochowski A. & Lisowski A. 2019 Physicochemical properties and agglomeration parameters of biogas digestate with addition of calcium carbonate. *Agronomy Research* **17**(4), 1568–1576. https://doi.org/10.15159/AR.19.161
Poulsen, H., Lund, P, Sehested, J, Hutchings, N & Sommer, SG. 2006. Quantification of Nitrogen and Phosphorus in Manure in the Danish Normative System. In: *12th Ramiran International Conference 'Technology for Recycling of Manure and Organic Residues in a Whole-Farm Perspective'. DIAS Report no. 123.* Research Centre Foulum, Denmark: Danish Institute of Agricultural Sciences, vol. **II**, pp. 105–107.
Priekulis, J., Melece, L. & Laurs, A. 2019. Most appropriate measures for reducing ammonia emissions in Latvia's pig and poultry housing. *Agronomy Research* **17**(3), 797–805.
Rodhe, L. & Jonsson, C. 1999. *Provtagarutrustning för fastgödsel. [Sampler for solid manure]*. Swedish Institute of Agricultural and Environmental Engineering Report no. **252**, Uppsala, Sweden, (in Swedish).
Shalavina, E., Briukhanov, A., Uvarov, R. & Vasilev , E. 2017. Method for selection of pig manure processing technologies *Agronomy Research* **15**(3), 866–876.
Shalavina, E.V., Uvarov, R.A., Vasilev, E.V & Freidkin, I.A. 2019. Pilot study findings of bio-fermentation of the solid fraction of pig manure. *Technologies, machines and equipment for mechanised crop and livestock production* **99**, 326–334 (in Russian).
Sindhöj, E., Kaasik, A., Kuligowski, K., Sipilä, I., Tamm, K., Tonderski, A. & Rodhe, L. 2013. *Manure Properties on Case-Study Farms in the Baltic Sea Region.* Report 417, Agriculture & Industry, JTI – Swedish Institute of Agricultural and Environmental Engineering. Uppsala, Sweden. ISSN-1401-4963.
Uvarov, R., Shalavina, E., Vasilev, E. & Freidkin, I. 2019. Optimisation of substrate based on solid fraction of pig manure for solid-phase aerobic fermentation. *Technologies, machines and equipment for mechanised crop and livestock production* **100**, 187–196 (in Russian).
Valge, A., Dzhabborov, N. & Eviev, V. 2015 *Fundamentals of statistical processing of experimental data for research in mechanisation of agricultural production with examples in STATGRAPHICS and EXCEL.* Saint Petersburg; Elista: Kalmyk Univ. Publ. 140 pp. (in Russian).