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Microstructural and chemical analysis of selected poultry bedding materials — potential substrates in agricultural biogas production technologies

Abstract
The research results concerning microstructure and chemical composition of selected post-processed poultry beddings derived from industrial-scale poultry breeding are presented. It was found, that the proper trend is providing the optimal conditions in respect to bred-animals comfort. The highest concentration of biogenic elements — especially nitrogen and potassium — was observed for the samples of poultry manure premixed with the straw. High quality of bedding biomass influences the inhibition of poultry-manure decomposition processes advantageously. In effect, biogas yield increases (due to C/N adjustment), in spite of the fact that increase in ammonium nitrogen concentration simultaneously inhibits the methane fermentation process.

Keywords: agricultural biogas, poultry breeding, bedding biomaterials, chemical analysis, microstructural analysis.

1. Introduction

Poultry manure premixed with bedding biomaterial may represent important for global economy segment in market of substrates suitable for agricultural biogas production (Dalkılıc et al, 2015; Zhongqi et al., 2016). Considering the diversified chemical composition and potential possibilities of co-synthesis of different substances in the methane fermentation environment, which may inhibit the anaerobic fermentation processes, as well as represent gaseous side-products limiting the applicability and quality of agricultural biogas, analysis of their composition may provide valuable and essential information crucial for their potential usability as the substrates for biogas plant. Bedding biomass cumulates biogenic components present in poultry manure. Especially high contents of biogenic substances and biogenic elements are observed in poultry manure with bedding biomaterial of high affinity for their sorption, what results from high ability to absorb the moisture and to sorb biogenic substances. Another important factor is application of heated floor in poultry breeding technology. It strongly influences water evaporation intensity, thus limited chicken manure decomposition in poultry breeding is observed.

As the subject of presented research some poultry industry wastes were selected. These included:

- mix of poultry manure with sawdust,
- mix of poultry manure with straw,
- post-processed poultry beddings derived from broiler poultry-breeding on heated floor,
- post-processed poultry beddings derived from broiler poultry-breeding with preprocessing — diverse aeration (composting) time ("fresh", 6 and 12 weeks) on a manure plate (preliminary preprocessing of substrate in aerobic conditions),
- post-processed poultry beddings partially dried and "wet" (aerated).

2. Physicochemical analyses

Chemical composition analysis of the post-processed poultry beddings — biomaterials premixed with poultry (hens, turkeys) manure which may represent valuable substrates in biogas production were done at Silesian University of Technology, Gliwice, Poland. It was based on both classical chemical and instrumental analysis.

Incineration of samples was done according to PN-EN 12880:2004 norm. Microstructure analyses were done with the use of scanning electron microscope and chemical composition analyser EDS. The results are presented in sections 2.1–2.5.

2.1. Poultry manure premixed with sawdust

Wheat and rye straw are the most often used as the bedding in industrial-scale poultry breeding. Long straw is responsible, however, for cutting of crow's feet. From this reason some new bedding biomaterials are required like: crumbled straw, sawdust, grass pellets or *triticum spelta* husks. Such beddings influence the poultry development advantageously. Analysis results covering samples of poultry manure premixed with the bedding represented by sawdust — dry mass, organic mass and inorganic mass contents — are presented in Table 1.

Table 1. The quantitative analysis results of the poultry manure samples premixed with the bedding represented by sawdust.

Poultry manure with sawdust	Dry mass [%]	Organic mass [%]	Inorganic mass [%]
Sample 1	56.697	85.603	14.396
Sample 2	58.634	86.702	13.298
Sample 3	57.725	85.172	14.828
Mean	**57.685**	**85.826**	**14.174**

Results of limited elemental analysis of incinerated samples are presented in Table 2. One can notice high concentrations of calcium, phosphorus and sulphur. This is of primary importance for poultry-manure behaviour during methane-fermentation process.

Table 2. Results of elemental analysis of chosen incinerated samples [%]

Element	Test 1	Test 2	Test 3	Test 4	Test 5
C	1.60	1.53	3.73	1.59	0.77
O	34.46	37.75	43.70	41.05	33.11
Na	2.50	1.26	3.23	4.69	2.74
Mg	2.91	2.34	14.02	2.27	2.43
Si	0.78	–	0.51	1.49	0.37
P	7.15	4.54	4.15	8.39	10.17
S	2.40	4.47	2.71	1.90	2.49
Cl	6.21	5.14	5.21	4.73	5.19
K	22.20	28.94	14.83	16.24	20.43
Ca	16.54	11.34	7.21	15.72	20.18
Fe	1.45	1.89	0.69	0.81	0.47
Zn	1.46	–	–	0.48	0.66
Mn	–	0.79	–	0.36	0.53
Al	–	–	–	0.30	–

Table 3. The quantitative analysis results of the poultry manure samples premixed with the bedding represented by the straw.

Poultry manure with the straw	Dry mass [%]	Organic mass [%]	Inorganic mass [%]
Sample 1	47.031	85.342	14.685
Sample 2	48.012	85.438	14.562
Sample 3	49.56	85.766	14.234
Mean	48.201	85.515	14.485

Table 4. The qualitative analysis results of incinerated samples [%]

Element	Test 1	Test 2	Test 3	Test 4	Test 5
C	4.07	2.30	2.80	1.18	2.06
O	34.17	32.91	33.95	31.81	33.49
Na	1.47	1.79	1.11	1.68	2.70
Mg	3.29	3.49	2.46	2.35	3.85
Si	0.63	2.23	0.36	0.69	0.90
P	7.19	7.27	7.13	8.42	9.49
S	1.69	0.98	0.90	1.71	1.32
Cl	6.80	4.39	6.47	5.90	4.56

Element	Test 1	Test 2	Test 3	Test 4	Test 5
K	21.05	21.78	23.95	23.62	19.74
Ca	18.53	20.94	19.54	21.02	18.78
Fe	1.10	1.91	1.34	1.61	1.28
Zn	–	–	–	–	1.37
Mn	–	–	–	–	0.46

2.2. Poultry manure premixed with the straw

Application of rye, wheat and barley straw as the bedding biomaterials is the most popular. Moreover, various straw modifications are carried out for poultry losses reduction. Too crumbled dry straw is responsible for generation of dust in the chicken coop. The analytical results of poultry manure samples premixed with bedding biomaterial represented by straw — dry mass, organic mass and inorganic mass contents are presented in Table 3. Concentrations of selected elements in incinerated samples of poultry manure premixed with the bedding represented by the straw are presented in Table 4. Concentrations of selected elements in incinerated samples of pure straw (comparative, reference analysis) are presented in Table 5.

Table 5. The qualitative analysis results of incinerated samples of pure straw

Element	Test 1	Test 2	Test 3	Test 4	Test 5
O	30.39	31.24	18.07	30.57	29.47
Ca	2.85	4.01	10.22	4.73	13.80
Si	3.19	4.81	3.35	3.56	3.80
C	6.58	6.82	3.00	3.76	3.06
K	30.39	26.97	36.13	25.80	27.98
Mg	–	0.15	0.19	0.15	0.14
S	0.93	2.01	3.68	3.80	2.64
Cl	24.74	18.31	20.92	16.02	13.75
P	–	–	1.75	0.36	1.76
Fe	–	–	–	–	–
Na	4.65	5.69	2.68	5.55	3.58

High concentrations of chlorine and potassium in straw samples is evidently clear. It is important during its burning.

2.3. Post-processed poultry bedding derived from breeding broiler poultry on a heated floor

The most recent solutions in broiler poultry breeding technology are connected with using of heated floor. It is of essential importance for ammonia emission and dust emission levels in a chicken coop. Concentrations of selected elements in incinerated samples of poultry manure derived from broiler poultry breeding on a heated floor are presented in Table 6 (bedding — raw straw — component of post-processed sample).

Table 6. Concentrations of selected elements — post-processed poultry bedding derived from broiler poultry breeding on the heated floor (bedding material — raw straw)

Element	Test 1	Test 2	Test 3	Test 4	Test 5
O	39.86	38.15	43.67	42.60	48.89
Ca	6.18	4.16	5.57	9.77	3.04
Si	30.26	31.29	28.57	24.65	32.51
C	3.54	5.70	4.67	3.82	3.67
K	19.86	17.75	15.45	15.08	10.38
Mg	–	0.60	0.58	1.20	0.33
S	–	0.59	0.22	0.10	–
Cl	0.74	1.35	1.26	0.39	1.19
P	–	–	–	2.40	–
Na	0.39	0.42	–	–	–

One should take into account a high concentration of potassium in poultry manure premixed with the straw bedding material. Figure 1 present microstructure of incinerated sample of poultry manure premixed with the straw bedding material together with the analysis of its surface chemical composition using EDS method are presented.

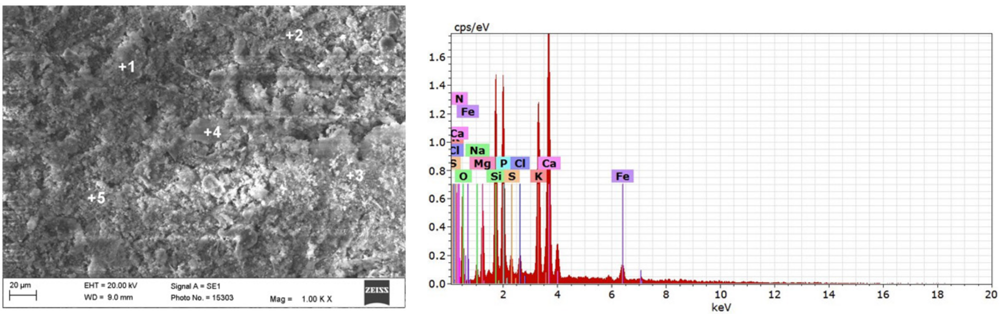

Fig. 1. Microstructure of incinerated sample of poultry manure premixed with the straw bedding material with surface chemical analysis using EDS method

2.4. Post-processed poultry bedding derived from broiler poultry breeding with additional preprocessing before methane fermentation

Poultry manure derived from chicken coop with heated floor is dry — represented by high value of dry mass. Methane fermentation of such manure requires thus strong initial dilution. Concentrations of selected elements in incinerated samples are presented in Table 7 (post-processed poultry bedding derived directly after breeding cycle termination), in Table 8 (post-processed poultry bedding after 6 weeks of exposition to aeration on a prism — partial composting), as well as in Table 9 (post-processed poultry bedding after 12 weeks of exposition to aeration on a prism).

Table 7. Concentrations of selected elements in incinerated samples — post-processed poultry bedding derived directly after breeding cycle termination

Element	Test 1	Test 2	Test 3	Test 4	Test 5
O	39.72	34.62	39.22	31.67	35.41
Ca	10.29	8.98	10.74	9.05	6.68
Si	0.75	–	0.94	2.44	–
C	2.95	2.24	2.71	2.38	8.14
K	30.90	34.32	30.27	34.52	32.46
Mg	2.95	2.92	3.88	2.49	2.64
S	0.99	1.09	1.29	4.24	1.49
Cl	4.30	4.40	5.17	4.58	7.39
P	4.66	3.91	3.98	4.74	3.58
Fe	0.53	0.78	–	0.57	0.42
Na	1.97	1.45	1.80	2.09	1.79
Mn	–	0.89	–	–	–

Table 8. Concentrations of selected elements in incinerated samples — post-processed poultry bedding after 6 weeks of exposition to aeration on a prism

Element	Test 1	Test 2	Test 3	Test 4	Test 5
O	40.50	37.39	41.66	28.39	30.42
Ca	12.90	11.85	16.31	12.35	12.35
Si	0.21	–	0.48	–	0.55
C	3.70	4.64	3.11	9.14	2.44
K	21.28	23.20	22.82	28.20	32.47
Mg	4.31	4.17	3.89	4.67	3.93
S	1.60	1.36	0.41	1.23	1.60
Cl	3.86	5.16	3.81	7.19	5.44
P	6.34	6.50	5.29	5.33	4.59
Fe	0.58	0.56	0.65	0.71	2.08
Na	4.05	3.75	1.57	1.69	1.47
Mn	–	0.22	–	–	–
Zn	0.69	1.13	–	1.10	2.65

Table 9. Concentrations of selected elements in incinerated samples — post-processed poultry bedding after 12 weeks of exposition to aeration on a prism

Element	Test 1	Test 2	Test 3	Test 4	Test 5
O	35.04	34.24	33.31	27.92	17.89
Ca	15.64	13.91	16.33	18.58	20.90
Si	0.59	0.70	–	–	–
C	1.61	2.03	2.22	1.58	0.69
K	31.53	27.06	26.56	27.75	33.28
Mg	3.09	4.03	4.78	3.59	1.64
S	1.49	1.68	1.49	2.26	4.88
Cl	5.22	6.20	5.98	8.07	5.53
P	4.11	3.50	4.80	5.60	5.13
Fe	0.50	1.38	0.59	1.28	0.70
Na	1.18	1.61	1.36	1.34	0.50
Mn	–	0.06	0.59	–	1.94
Zn	–	3.60	2.00	2.02	6.92

A significant level of mineralization of poultry manure aerated longer on a manure plate should be stressed — it is now more susceptible to decomposition in initial process phase.

2.5. Post-processed poultry bedding derived from broiler poultry breeding — “dry” and “wet” (aerated)

Post-processed poultry bedding (mixed with manure), being the subject of preliminary preprocessing, is decomposed during the first stage of anaerobic fermentation significantly faster than “dry” poultry manure. Preparation of the post-processed poultry bedding (with manure) for methane fermentation is also crucial in respect to increase in biogas yield. An increase in methane fermentation intensity may result from preliminary aeration of poultry manure (composting). It may be done as early as during exposition of manure on the manure plate. Long-exposition of manure to preliminary, partial composting process makes that it is decomposed (fermenting) with higher rate.

Table 10. Concentrations of selected elements in incinerated samples of digestate from the “fresh” post-processed poultry bedding — substrate for methane fermentation process

Element	Test 1	Test 2	Test 3	Test 4	Test 5
O	33.99	34.06	21.30	38.83	37.32
Ca	10.24	9.49	9.53	9.89	11.17
Si	0.87	–	–	0.71	1.17
C	4.88	3.09	1.75	5.05	5.63
K	31.33	36.48	49.80	28.62	28.89
Mg	1.39	0.46	–	1.88	1.98

Element	Test 1	Test 2	Test 3	Test 4	Test 5
S	0.08	–	0.46	0.28	0.80
Cl	5.77	5.05	9.01	4.58	5.63
P	2.57	1.82	1.76	2.64	3.36
Fe	0.86	4.01	3.05	2.28	1.16
Na	2.03	0.81	–	2.78	2.36
Mn	–	0.80	0.70	–	–
Zn	–	3.93	2.64	2.46	–

Table 11. Concentrations of selected elements in incinerated samples of "dry" post-processed poultry bedding — substrate for methane fermentation process

Element	Test 1	Test 2	Test 3	Test 4
C	2.94	6.04	2.82	6.65
O	35.37	41.76	34.27	51.01
Na	–	0.88	0.62	1.70
Mg	–	0.97	0.24	0.54
Si	–	–	–	15.18
P	–	1.84	0.19	1.51
S	2.94	2.23	2.93	0.73
Cl	5.75	4.67	3.98	2.74
K	7.96	4.72	5.35	10.92
Ca	44.08	35.54	48.52	8.57
N	0.95	1.34	1.08	0.46

Concentrations of selected elements in incinerated reference sample ("fresh" post-processed poultry bedding — collected directly after breeding cycle termination) are presented in Table 10 and 11 (data for "dry" post-processed poultry bedding) and in Table 12 (data for "wet" — aerated post-processed poultry bedding).

3. Conclusions

From the biogas-technology point of view the results obtained suggest the necessity of further research and observations connected with rational selection of the optimal, in the given poultry breeding technology and economical conditions, biomaterial for bedding, followed by controlled run of biogas biosynthesis process, optionally connected with the possibility of simultaneous manufacturing of natural fertilizers. Based on the resulting analytical data one can conclude, that the highest concentrations of biogenic elements were reported for the samples of poultry manure with straw bedding. These elements contents, especially of nitrogen and potassium, may result from substrate such as straw and grass pellets. However, manure premixed with the sawdust shows different course in batch anaerobic fermentation. High ammonium nitrogen content in post-fermented residues makes its turning back to the biogas production cycle difficult (Bharathiraja et al. 2018). Too high concentration of ammonium nitrogen inhibits the biogas production process (Nakakubo et al. 2008; Walker et al., 2011; Tao et al., 2015).

Table 12. Concentrations of selected elements in incinerated samples of "wet" — aerated post-processed poultry bedding — substrate for methane fermentation process

Element	Test 1	Test 2	Test 3	Test 4
C	8.06	8.18	1.68	1.74
O	32.13	51.88	32.46	29.11
Na	2.75	0.76	2.34	3.11
Mg	4.26	0.86	3.85	5.29
Si	1.19	–	1.56	2.30
P	9.62	2.10	11.46	12.65
S	1.60	0.51	1.54	1.68
Cl	5.16	1.32	3.11	3.76
K	18.80	6.69	23.96	19.59
Ca	13.48	27.70	15.61	17.85
Fe	0.71	–	0.78	1.11
N	0.65	–	0.96	0.58
Mn	0.40	–	0.69	0.61
Zn	0.14	–	–	0.61
Cu	0.54	–	–	–

However, one should also take into account the favourable for economy and environment combination of recycling of this troublesome side-products of poultry breeding industry with production of the ecologically friendly biogas. High quality of bedding biomaterial in chicken coop influences the animals comfort and inhibition of uncontrolled, spontaneous poultry manure decomposition. It influences the biogas yield advantageously (correction of technologically important C/N ratio), in spite of the fact that rise of ammonium nitrogen content inhibits clearly the anaerobic fermentation process. This way preliminary separation of poultry manure from bedding biomaterial is not necessary, thus technological process costs can be significantly reduced making this multicomponent substrate more attractive for the biogas producers.

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