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NEW POSSIBILITIES OF USING THE ASH RESULTING FROM THE ENERGY RECOVERY OF POULTRY LITTER WITHIN THE CIRCULAR ECONOMY CONCEPT

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Abstract

The increase in domestic poultry production in Romania is a result of the efforts our country is making to limit imports from other countries on one hand, and the development of the poultry sector through domestic investments, on the other hand. In 2022, poultry meat production increased by over 6%, and further increases are expected. In the same dynamic, the amount of aviary waste generated by poultry farms is also increasing, and in these conditions, it is obvious for our concerns to focus on the recovery, recycling, and utilization of avian waste. In this paper, we will present new possibilities for the utilization of ash resulting from the incineration of avian waste. In this case, avian waste is used as fuel, either in addition to biomass or municipal waste, to produce thermal energy.

Key words: *circular economy, incineration waste products, poultry litter ash.*

INTRODUCTION

According to OECD-FAO Agricultural outlook 2019-2028, in high-income countries, growing awareness of health and sustainability issues is increasingly shaping consumer decisions. This effect has contributed to the rising popularity of lean meats, such as poultry (Korver, 2023). Developed countries are expected to expand per capita poultry food use by nearly 2 kg/capita to reach 31 kg/capita by 2028. Health concerns will motivate corresponding increases in poultry consumption, with Canada increasing per capita food use of poultry by 1.2 kg/capita by 2028, and New Zealand adding 1.6 kg/capita over the same period. Similar substitutions across meat types are projected for the European Union, Norway, Switzerland, and Australia (OECD/FAO, 2019).
Therefore, the production of poultry litter will also increase, potentially aggravating the problems related to management of this waste (Fahimi et al., 2020).

Today, worldwide, several ways of utilizing aviary waste are known, the most common of which include:
- production of organic fertilizers: poultry waste can be composted and turned into nutrient-rich organic fertilizers;
- biogas production: poultry waste can be used in biogas production. In this case, the waste is digested anaerobically, which produces biogas (consisting of methane and carbon dioxide), which can be used to generate electricity and heat;
- thermal energy production: depending on the method of making the poultry bed, the waste can contain a significant amount of organic matter, in which case it can also be used in waste incinerators to produce thermal energy (Lăzăroiu, 2020);
- the production of construction materials: the ash resulting from the incineration of bird waste can be used in the construction materials industry as an additional raw material, either in the manufacture of construction materials made

in the form of burned ceramics, or in the manufacture of construction materials such as concrete.

Organic waste (excrement) from poultry farms is classified as solid organic waste (more than 15% dry matter). Due to the high content of phosphates, these wastes can be used as such as agricultural fertilizers, but the main drawback is the waste of straw, sawdust, etc. which, after spreading on the agricultural soil, can be entrained in the air currents, and thus become the environment polluting factors. In Romania, the recovery of this type of waste is done in such a way that unwanted side effects are partially avoided through preliminary stages of natural drying and fragmentation (shredding), respectively distribution on land in periods preceding the rainy or snowy seasons.

To eliminate the risks of ecological contamination, in many countries it is practiced disposing of aviary waste by incineration, with recovery of produced energy. In this way, the main advantages obtained consist in significant reduction of the waste ash volume resulting after combustion representing less than 30% of the initial volume, as well as the production of thermal energy. The value of agricultural fertilizer does not change essentially (the content of chemical compounds of phosphorus being residual), but the potential for deflation (entrainment in air currents) is considerably reduced.

MATERIALS AND METHODS

This paper presents the results of research activity carried out within the project *Thermal Processing of P-rich ashes aiming for high-grade phosphorus products (PHIGO)*, implemented by a European consortium that also includes the National University of Science and Technology Politehnica Bucharest (UNSTPB). “Constantin Brancusi” University of Targu Jiu (UCB), a subcontractor of UNSTPB, is carrying out research at laboratory level within the project regarding the evaluation of potential use of residues obtained after P recovery through thermal reduction processes. In fact, the purpose of the work carried out in laboratory was to evaluate the potential use of the ash resulting from the combustion of poultry waste after the extraction of P by reductive heat treatment and to identify areas of use for these waste materials.

The ashes that are the subject of the research within the PHIGO project come from the incineration of poultry litters exhausted after the cycles of use in some poultry farms, and some sewage sludge from Turkey. P-rich ashes were collected from different companies that use poultry litter recovered from the combustion chamber as bottom and fly ash, such as Güres Energy, H29 Energy and Beypi. Additional samples were provided by INEVA and MIMSAN companies that incinerate sewage sludge. The samples used by UCB team in the present study resulted after thermal extraction processes performed by Swerim company, Sweden, the coordinator of the PHIGO project.

To evaluate the potential use of P thermal extraction residues, the Physical-Mechanical Testing Laboratory of UCB team received 12 individual preliminary samples of residual ash accompanied by the sheets containing the results of determinations of chemical oxide composition carried out by X-ray fluorescence analysis (Table 1).

Within UNSTPB, the fixed carbon content of the samples was previously determined following proximate analysis (Table 2). Considering the small amounts of residual samples obtained after heat treatment sent, the cumulation of elementary samples was established, by grouping the initial ones into two series of average samples, depending on the compositional specificity, according to the data entered (Table 3):

- medium sample series 1: ashes with CaO above 40%;
- medium sample series 2: ashes with CaO below 40%.

In addition, with residual ash, the laboratory works also used gray fat clay, which is a mining waste from the excavation work in the lignite quarries in the Gorj area and is currently used as a raw material for the manufacture of building bricks in within MACOFIL S.A. from Targu Jiu. The oxide chemical composition of the gray fat clay (Tables 4 and 5) shows the physical properties of the gray Rovinari clay, Romania (LIFE10 ENV/RO/00079 Project, 2012).

Table 1. Oxide chemical composition of the rezidual ash samples

Sample/oxide	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R14**	**R15**	**R16**	**R17**	**R18**
CaO	41.29	43.23	24.63	29.35	33.45	25.28	46.08	44.89	42.91	40.63	44.19	41.72
SiO_2	30.03	30.27	12.93	20.88	18.08	12.60	14.11	17.45	16.59	13.52	12.98	28.24
K_2O	3.18	4.22	25.89	1.83	2.69	20.45	7.74	2.38	8.06	5.45	9.79	5.26
S	3.16	2.42	12.41	2.49	2.26	10.84	6.04	2.08	5.71	1.85	5.96	2.27
P_2O_5	2.59	2.91	9.98	3.11	7.63	9.58	8.82	6.88	6.98	14.52	10.72	4.20
MgO	2.30	2.10	4.01	1.45	3.31	4.50	3.93	4.29	3.59	2.95	3.78	1.99
Al_2O_3	1.33	0.87	1.11	6.51	5.46	2.12	0.64	0.79	0.63	0.58	0.54	0.62
Na_2O	0.69	0.74	1.80	0.25	1.10	1.54	1.02	0.69	1.17	1.00	1.06	0.82
Fe_2O_3	0.57	0.35	0.94	6.43	4.95	1.54	0.65	0.67	0.67	0.58	0.60	0.40
TiO_2	0.05	0.03	0.08	0.75	0.85	0.24	0.04	0.06	0.04	0.05	0.04	0.03
MnO	0.15	0.15	0.42	0.30	0.20	0.47	0.31	0.27	0.31	0.24	0.30	0.16
SrO	0.10	0.02	0.04	0.04	0.11	0.05	0.12	0.11	0.11	0.10	0.12	0.02
Cl	0.04	0.06	5.12	0.05	0.04	1.83	1.45	0.03	1.33	0.33	2.18	0.31
CuO	0.02	0.02	0.05	0.30	0.06	0.05	0.04	0.03	0.04	0.03	0.04	0.02
Cr_2O_3	0.03	0.02	0.02	0.08	0.12	0.03	0.01	0.01	0.01	0.01	0.01	0.01
MoO_3	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NiO	-	-	-	0.02	0.19	0.01	-	0.01	0.01	0.01	0.01	0.00
CdO	-	-	-	-	-	-	0.01	-	-	-	-	-
ZnO	-	-	0.04	-	-	0.01	-	-	-			-

Table 2. Fixed carbon content of the residual ash samples (% wt.)

R7	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R14**	**R15**	**R16**	**R17**	**R18**
0.76	0.93	7.78	7.38	6.25	7.56	8.48	8.46	7.41	10.67	9.03	2.77

Table 3. Residual ash samples grouped according to compozitional criteria

Series 1		**Series 2**	
Sample	Weight, g	Sample	Weight, g
R7	15.4	**R9**	15.3
R8	17.0	**R10**	12.8
R13	15.8	**R11**	21.9
R14	17.1	**R12**	8.5
R15	14.9		
R16	21.1		
R17	16.4		
R18	10.7		

Table 4. Oxide chemical composition of gray fat clay (LIFE10 ENV/RO/00079 Project, 2012)

SiO_2	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**P.C.**
65.80	0.68	15.97	5.40	0.11	1.64	0.85	1.86	2.37	0.12	5.35

For the qualitative and quantitative analysis of the samples oxide composition the Thermo Scientific ARL PERFORM'X Sequential X-ray Fluorescence (XRF) Spectrometer of the UNSTPB was used. Fixed carbon was analysed using STAS 5268: 1990.

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Table 5. Physical properties of gray clay (LIFE10 ENV/RO/00079 Project, 2012)

Plasticity (I_p)	26-37.8
Consistency (I_c)	0.69-0.86%
Natural moisture (w)	18.6-35.5%
Apparent volumetric weight (γ_a)	(175-194) kPa
Internal friction angle (φ)	13^0-26^0
Cohesion factor ©	(20-55) kPa

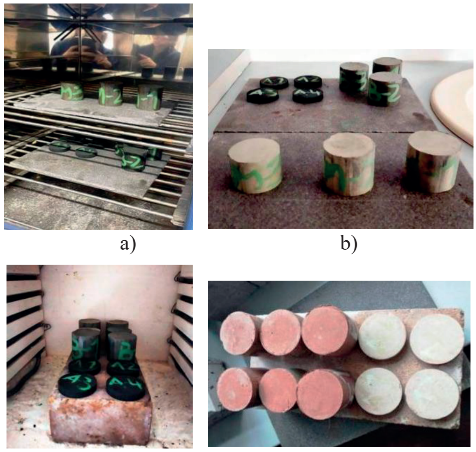
Using the materials presented previously, two experimental mixtures were made in the laboratory, according to the following dosage recipes (% by mass):
1. Compositional variant 1, marked A, with the following content:
   - Ashes of Series 1: 85.7%
   - Clay: 14.3%
2. Compositional variant 2, marked B, with the following content:
   - Ashes of Series 2: 11.5%
   - Clay: 88.5%.

At the same time, control/reference samples, marked M, were made from clay only.
From the two mixtures marked A (4 pieces marked A1, A2, A3, A4), B (3 pieces marked B1, B2, B3) but also from clay (3 pieces marked M1, M2, M3), compacted pieces were obtained by pressing in a metal mold, at the nominal pressure of 40 MPa (Figure 1). After compaction, the experimental pieces were kept for 48 hours at ambient temperature, then subjected to the heat treatment of drying in an electric laboratory oven for 8 hours at a temperature of 110°C ± 1°C. The dry samples were burned in an electric laboratory furnace at a temperature of 1000°C, with a thermal gradient of 5°C/min and kept for 2 hours at the maximum temperature (Figure 2).

a) b)

Figure 1. Obtaining of compacted specimens: a) Feeding mould; b) Pressing

Both in the raw state and after drying and burning, samples were weighed on a laboratory balance having precision of 0.1 g and measured to the nearest 0.1 mm (Figure 3).



a) b) c) d)

Figure 2. Experimental specimens thermal treatment: a) Drying; b) Dryed samples; c) Burning; d) Burned samples

Figure 3. Samples weightning and measuring

After burning treatment, the specimens were used distinctly, depending on the predetermined technological destination:

a. ***Samples marked A*** were manually fragmented, then ground in the Retsch ring mill to the advanced fineness of a cement powder (Figure 4) and tested to determine hydraulic cold setting ability (Figure 5).
Given the very small amount of processed sample, the hydraulic hardening ability of the ground sample was tested by wetting it with water and making a compact paste of spherical format (Figure 5). The spherical piece was placed on the base of the Vicat device, checking the hardening phenomenon, like the sample for cement paste (Figure 6).

a) b)

Figure 4. Grinding samples A:
a) Feed mill Retsch; b) Ground sample

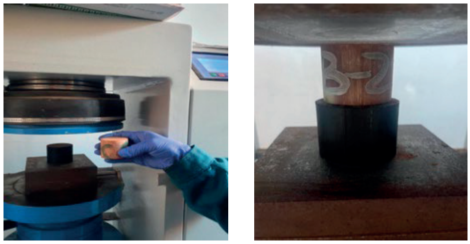
a) b) c)

Figure 5. Testing the hydraulic strengthing behaviour:
a) Powder wetting; b) Shaping compacted sample;
c) Spherical piece made from wetted powder

b. ***Samples marked B and M*** (burned cylinders) were subjected to the mechanical compressive strength test (Figure 7). The mechanical strength of the samples' marked B was evaluated in accordance with the provisions of Standard R EN 993-5:2001 test methods for dense shaped refractory products. According to it, the mechanical resistance to compression is determined by subjecting the samples to the action of the pressing force between the parallel flat platens of the test press of Accuracy Class 1, with the adjustment of the load loading speed of 2.5 MPa/second (Figure 7).

a) b) c)

Figure 6. Checking hardening of spherical piece:
a) Socket start; b, c) Socket end



a) b)

Figure 7. Determination of compression strength:
a) Automat pressing; b) Cylinder pressing

RESULTS AND DISCUSSIONS

At this moment the percentage replacement of natural aggregates such as aviary ash depends only on physical and mechanical characteristics of the final product. Since this is not hazardous waste, there are no concerns regarding the impact on the environment and the human health.

The test carried out on the samples marked A with the Vicat device indicated that the powder obtained by the fine grinding of the samples A burned at 1000°C has the property of cold hydraulic hardening.

The samples marked with B and M were subjected to the mechanical compression resistance test, the results being presented in Table 6.

Table 6. Compression strength of cilyndrical specimens burned at 1000˚C

Sample	Maximum force applied, MPa	Compression strength, Mpa
B1	48.0	24.47
B2	50.9	25.94
M1	49.5	25.23
M2	52.8	26.88

From data of Table 6, the mechanical strengths of the samples obtained with the addition of de-phosphated ash are like those of the samples without ash (reference samples), which indicates that this type of ash can be used as a degreasing additive in shaping mixtures, in situations where the processed clay (basic raw material) has a too high plasticity.

CONCLUSIONS

This paper presents some scientific preliminary research conducted with the aim of identifying other possibilities of using poultry litter ash than those already known. By finding practical solutions which does not provide leachate, allowing to save chemicals (used in wet methods) and avoid liquid waste, will enable closing the P loop in the EU P-strategy. The most important conclusions are presented below:

a. The residual ash resulting from the thermal treatment of poultry litter waste has a complex chemical composition, like other ashes from incinerated industrial waste. Compared to other waste from agri-food complexes, residual ashes stand out for their high content of calcium and phosphorus oxides.

b. The silico-calcium compositional basis of the ashes suggests the possibility of their utilization as alternative raw materials for the manufacture of Portland cement. An impediment in this direction is the high content of P_2O_5, a compound that persists with a significant weight even after the thermal processing carried out to recover phosphorus through thermal reduction.

c. Starting from the premise that the negative effect of the presence of phosphorus cannot be avoided in the direction of valorization in clinker, it was aimed to favor the formation of dicalcium silicate by ensuring a CaO/SiO_2 molar ratio of around 2 in the raw material, by mixing the ash with a clay silicate.

d. It was also tested the possibility of using ash as a degreasing additive in the clay raw material on the construction brick manufacturing process, as a substitute for natural quartzite sand in situations where lots of clay with too much plasticity are available.

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