Conversion technology of anaerobic digestates from biogas plants to fertilizer formulation

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The fertilizer industry is currently facing a crisis due to the availability and price of raw materials. However, this challenge presents an opportunity to utilize waste materials as alternative sources of nutrients. A promising raw material is the digestate from biogas production [1]. Biogas plants are becoming increasingly popular due to government incentives that promote renewable energy production [2]. Anaerobic digestion is a promising method of managing biological waste for material and energy recovery. Over the past 20 years, there has been a global increase in biogas production from 0.29 EJ in 2000 to 1.43 EJ in recent years [3].

Agri-food production relies heavily on synthetic nitrogen fertilization. Although the use of fertilizers increases yields, much of the nutrients are leached into groundwater or used by soil microorganisms, which generate NO2 (a greenhouse gas), which is more harmful than CO_2 [4]. To reduce GHG emissions, it is recommended that fertilizer use be reduced or that synthetic nitrogen be replaced with an organic form [5].

The digestate, a byproduct of biogas production, can be applied to crops as an organic fertilizer containing NPK components [6]. The concentration of these components is related to the type of waste and the conditions of the AD process, such as retention time and the amount of fresh water or recirculating liquid [6,7].

Raw digestate can be used for fertigation, which allows for simultaneous fertilization and irrigation of crop fields. However, the presence of pathogens, fungal spores, or anaerobic microorganisms carrying out further fermentation in the AD byproduct may pollute the environment and pose a risk.

The aim of the research was to develop a conversion technology for anaerobic digestates from biogas plants into fertilizer formulation. To achieve this, a method was developed to sanitize the raw material that was used in the fertilizer formulation. The digestates were treated with strong acids and inorganic bases in order to hydrolyze proteins into amino acids and short peptides. The resulting hydrolysates were used to prepare NPK fertilizer formulations with amino acids.

The acid hydrolysis of the digest was carried out at room temperature using a mixture of concentrated inorganic acids, namely H_2SO_4 and H_3PO_4. The acid mixture was added in portions until the pH<1.5. After acidification, the digest was left to react for 24 hours. The acid hydrolysate was neutralized with solid potassium hydroxide until the pH=5. The slurry was then centrifuged, and a foliar fertilizer was obtained from the liquid fraction. The laboratory-scale experiments were then scaled up to the large-laboratory scale.

The large-laboratory scale fertilizer was produced by slowly adding ash, resulting in less nitrogen loss during granulation operations. This makes it possible to reduce the nitrogen dose during application. Urea with a urease inhibitor was also used as the raw material for production. The use of ammonium nitrate generated higher nitrogen losses during the production process, and as a result, this raw material was rejected [8]. During the granulation process, nitrogen losses were about 7%, which is about 4% more than on the laboratory scale. Correction of the composition during granulation increased nitrogen (above 2%) and urea-derived carbon content (above 1%), so microbiological analysis was necessary [9]. The composition of the resulting fertilizer is shown in Table 1.

Table 1. *Multielement analysis of a formulation produced on a large-laboratory scale*

Macronutrients							
C	**N**	**P_2O_5**	**K_2O**	**N_2O**	**CaO**	**MgO**	**SO_3**
%							
1.34±0.13	2.06±0.21	20.3±3.1	0.862±0.129	0.587±0.088	17.3±2.6	3.78±0.57	3.68±0.55

Micronutrient					
B	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
mg/kg					
73.9±11.1	863±129	$4.16 \cdot 10^4 \pm 6.25 \cdot 10^3$	702±105	13.9±2.1	$3.50 \cdot 10^3 \pm 5.24 \cdot 10^2$

Toxic elements					
Cd	**Cr**	**Pb**	**Ni**	**As**	**Hg**
mg/kg					
2.70±0.41	108±16	48.3±7.3	41.4±6.21	4.42±0.66	0.0202±0.002

The proposed formulation meets the requirements for fertilizer products according to the EU Regulation. The product can be classified as a solid inorganic macronutrient fertilizer: simple solid inorganic macronutrient fertilizer - PFC 1(C)(I)(a)(i). The declared content of P2O5 should be >12%, and in the case of the obtained formulation, it was >20%, while the total content of sodium oxide (Na2O) does not exceed 40% (0.587%) [9]. Using an ash additive with a high content of micronutrients, such as Cu, Mn, Zn, and Fe (∑4.6%), ensures compliance with the regulation and provides a solution for soils depleted in trace elements [10]. Despite the high content of toxic elements in ash from incinerated sewage sludge, the produced fertilizer meets the mandatory requirements of the law (As<40 mg/kg, Cd<60 mg/kg P2O5, Pb<120 mg/kg, Ni<100 mg/kg, Hg<1 mg/kg). The total Cr content in the tested formulation was 108 mg/kg, and the chromium speciation analysis showed levels below 0.500 mg/kg Cr(VI), meeting the quality requirement of the current directive, which states that the chromium (VI) content should be less than 2 mg/kg [9].

Reclassifying the formulation as an organic-mineral fertilizer would require increasing the organic carbon content to >7.5%. A possible solution for the future could be to use a material containing organic matter in the granulation process, while meeting the other conditions.

The acid and alkaline hydrolysis used in the production process provided the possibility of obtaining products containing amino acids with plant growth-promoting effects. During the fertilizer production, a detailed nitrogen balance was carried out, which made it possible to observe nitrogen losses in the system. No losses were observed during the production of the liquid fertilizer. All streams were managed in the developed technology, and the technology is zero-waste following the circular economy strategy [7]. The study also focused on the nitrogen balance at each stage of waste-to-fertilizer conversion to reduce potential losses and emission risks.

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