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Digestate Potential to Substitute Mineral Fertilizers: Engineering Approaches

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Abstract. The study aims to define the potential and technological aspects of the digestate treatment for its application as a biofertilizer. Life cycle assessment methodology was used in terms of digestate quality management. The potential of nutrients, organic carbon, and useful microelements in the digestate allows for its consideration as a mineral fertilizer substitute and soil improver. The valorization of digestate as fertilizer requires quality management and quality control. Based on the research focus, the successful soil application of digestate post-treatment technologies was analyzed. Among the different commercial options for digestate treatment and nutrient recovery, the most relevant are drying, struvite precipitation, stripping, evaporation, and membranes technology. Comparing the physical and chemical properties of the whole digestate, separated liquid, and solid liquor fractions showed that in the case of soil application of granular fertilizer, nutrients from the digestate are released more slowly than digestate application without granulation. However, realizing this potential in an economically feasible way requires improving the quality of digestate products through appropriate technologies and quality control of digestate products. To support the manufacture of quality digestate across Europe, the European Compost Network developed a concept for a pan-European quality assurance scheme.

Keywords: anaerobic digestion, climate change, life cycle assessment, soil degradation, sustainable land management, waste utilization, industrial diversification.

1 Introduction

Biogas reactors (BRs) are designed to produce methane from organic waste by anaerobic digestion (AD). BR produce leftovers, also known as digestate that has been successfully used as biofertilizer due to their high contents of mineralized Nitrogen (N), Phosphorus (P), Potassium (K), and organic materials [1]. Recycling organic materials to land is considered the best practicable environmental option in most circumstances, completing both natural nutrient and carbon cycles. Organic materials are valuable sources of major plant nutrients, essential for plant growth and sustainable crop production. Organic materials also provide a valuable source of organic matter, improving soil water holding capacity, workability, structural stability, etc. [2]. Digestate reduces the potential for soil erosion and improves productivity by increasing the soil organic matter and soil fertility and supplying additional nutrients [3].

Digestate is normally used as a biofertilizer without any further processing, substituting industrially produced mineral fertilizers. However, the need for efficient nutrient management, required by regulations on manure application in high livestock density areas, along with depletion of the finite reserves of phosphorous and potassium, make a recovery and recycling of nutrients [4].

Effective use of digestate is exceptionally relevant in Ukraine. The developed agro-industrial sector of Ukraine's economy, with a large share of agricultural land, requires considerable fertilizers. Actual management practice and land ownership during the years of Ukraine's independence have had a negative impact on soil fertility, which is resulted into the loss of large humus proportion, imbalance of nutrients content, soils acidification and alkalinity, deficits of mobile forms of phosphorus, potassium, and microelements, chemical and radiation pollution, and erosion. These conditions are found in intensive production with the dominant use of mineral fertilizers and the critical fall in the volume of organic fertilizers application [5].

Digestate is highly suitable as an organic fertilizer or soil improver. In Ukraine, digestate is currently produced at least on 26 biogas plants in the agro-industrial complex. The primary raw materials used are cattle and swine manure, poultry litter, maize silage, and sugar beet pulp. One example of small biogas plants is the Integro company biogas plant, which digests poultry manure.

The specific use of raw materials for biogas production amounts to approximately 1.9 tons for each produced MWh of gross biogas energy [6]. Thus, according to reasonably approximate estimates, the total formation of raw digestate in Ukraine is 1.5–1.6 mln tons per year as of 2020.

Practically any products, by-products, and wastes of agro-industrial production of organic origin can be raw materials for biogas production and, therefore, the source of digestate. Typical feedstock for biogas plants can be of plant and animal origin (animal excrements, agricultural residues, and by-products, organic wastes from food and agro-industries, industrial organic wastes, organic fraction of municipal solid waste, food waste, sewage sludge, energy crops). Different types of substrates can influence the nitrogen concentration, share of ammoniacal nitrogen, total organic carbon (TOC), total solids (TS) content, volatile solids (VS) content, and VS/TS ratio.

2 Literature Review

The addition of digestate increases the soil nutrient levels (N, P, K) and microbial diversity [7, 8]. Digestate as soil improver must be suitable for organic matter content according to the EU standards on fertilizer properties. Among the most significant and necessary organic material carbon and nitrogen have a key role in microbiological processes in the soil as well as carbon is the most widely used energy source. The efficiency of agronomic use depends on their relative ratios. Amount of N as well as N form, organic or mineral, effects on digestate potential as fertilizer [7].

The application of digestate increased soil nutrient supply with improvements in topsoil total N, extractable P and extractable Mg ($P<0.05$ at 4 of the 7 sites for each of these nutrients), extractable K ($P<0.05$ at 6 of the 7 sites), and extractable S ($P<0.05$ at 3 of the 7 sites) [9].

Digestate varies in its nutrient content, depending on the substrates, nature of the anaerobic digestion process and post-digestion treatment. Digestate is an excellent source of readily available N (i.e., ammonium) which is potentially available for immediate crop uptake. Food-based digestate typically contains around 80 % of its total N content as rumen ammonia nitrogen (RAN), compared with around 70 % for pig slurry and 45 % for cattle slurry. Digestion of livestock slurry will typically increase RAN by around 10 % of the total N content [10]. However, an increase of RAN while digesting such materials like straw, food wastes is much higher due to less RAN content in raw matter. RAN increase can reach 70–80 % for these kinds of materials.

Digestate addition in the soil is more effective than mineral fertilizers used to increase available P for plants. Since P deficiency is a significant nutrient problem in calcareous soils, where high pH and carbonate content in the soil makes P less accessible to plants, adding biofertilizers is an adequate strategy to alleviate the deficit of P [11].

Additionally, digestate contains small quantities of trace elements, with the amounts present depending on concentrations in the feedstocks used. However, digestate could also contain unwanted materials and contaminants of biological, chemical, or physical nature.

Feedstocks from agriculture and human food waste are, in most cases, low in chemical impurities [12]. Nevertheless, stringent quality requirements for digestate also imply strict control of these materials. Two categories of chemicals are particularly concerned for the quality of digestate used as fertilizer, heavy metals (HM), and organic pollutants.

The effect of repeated digestate and compost applications on soil and crop quality was carefully studied by Bhogal et al. in the work package [9]. Obtained results showed stability in the concentration e of heavy metals in the topsoil after digestate addition except for topsoil total and extractable Cu. Soil treatment with repeated digestate addition had little effect on soil organic contaminant compound (OCC) concentrations, but the concentration of polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, and phthalates and concentrations were low or at the limits of analytical detection. Besides this, digestate can decrease the concentration of Cr in the soil due to the potential redox reduction based on microbial activity improving after digestate application. Digestate addition provides Pseudomonas, Microbacterium, and Bacillus development that could reduce Cr(VI) to Cr(III) resulting in the bioavailability decrease and immobilization of Cr(VI) for plants [13].

The content of HM in digestates from AD plants processing feedstock from agriculture, food waste, and residues from food processing is normally within the suitability of agricultural fertilizers [14]. Nevertheless, technical and monitoring strategies that could reduce polluting hazards of the digestate before soil application would avoid soil contamination and prevent emissions.

The main aim of this study is to define the potential and technological aspects of the digestate treatment before its application as a biofertilizer. More specifically the focus is on the specific research tasks:

1) to propose a life cycle assessment methodology for digestate quality management;

2) to research all factors, particularly engineering approaches, that must be important to improve the quality and ecological safety of digestate as biofertilizer;

3) to develop the recommendation for soil application of main types of digestate-derived products and provide a quality assurance scheme for them.

Given the ever-increasing demand for energy in recent years, there is an urgent need to invest in clean and sustainable forms of energy. In this way, it will be possible to ensure that the energy needed by humanity around the world is sufficient. In particular, biomass energy can provide significant economic benefits, and guarantees are formed to monitor the mitigating impact on the environment [15].

3 Research Methodology

3.1 Digestate quality indicators

The quality of digestate as organic fertilizer could be described by the four main indicators, namely nutrients content, phase state, stability, and impurities content (Figure 1).

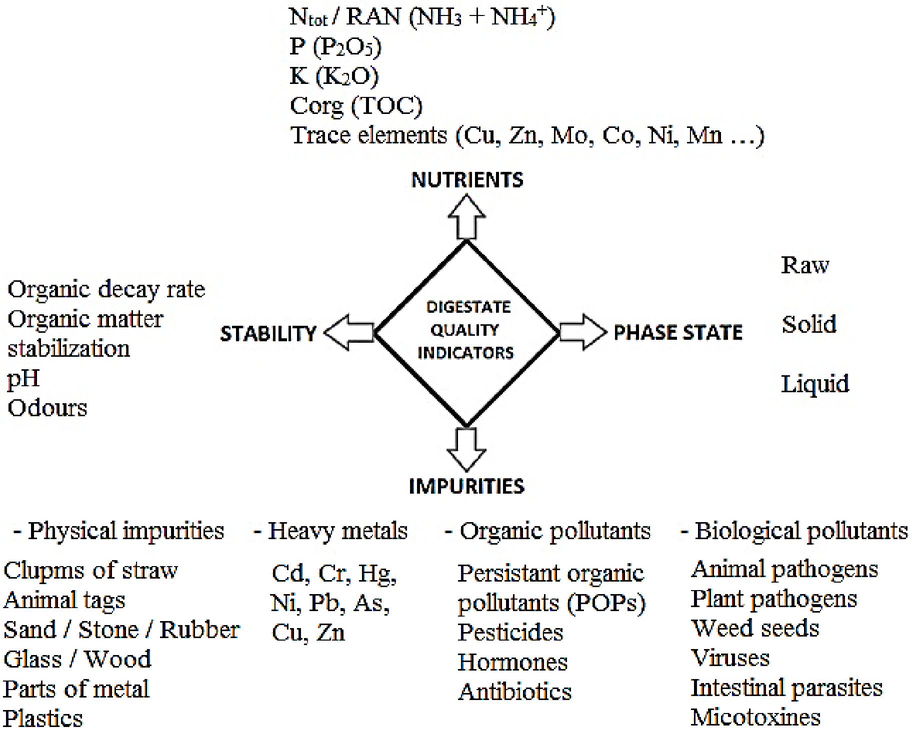


Figure 1 – Digestate quality indicators

The content of nutrients, humic substances, and trace elements in the digestate determines its fertilizing value. Simultaneously, the over-content of certain types of pollution impairs its commercial value, limits the list of applications, or makes it impossible to use it further without additional processing. To define how to improve the quality of digestate quality control system can be used.

3.2 Digestate quality management

Life cycle assessment methodology was used in terms of digestate quality management. The production and recycling of digestate as fertilizer requires quality management and quality control throughout the whole life cycle of AD, from the production of the AD feedstock until the final utilization of digestate as fertilizer. Quality management implies the use of high-quality feedstock, pre-processing of specific feedstock types, close control of the AD process, and process parameters affecting digestate quality, digestate processing, declaration, and optimal storage and application as fertilizer. The overall matrix for digestate quality management can be presented in Figure 2.

There are two main ways how to manage digestate quality, namely prevention and processing. The rule of thumb is that if efficient pollutant removal cannot be guaranteed either by pre-treatment or through the AD process, the material must not be used as feedstock in biogas plants whose digestate is used as fertilizer or for other agricultural purposes.

Prevention methods combine raw materials quality control at the stages of their formation in technological processes, collection, transportation, and storage. Getting into raw materials unwanted components such as sand, stones, plastic, other synthetic materials can be avoided by quality control of technological processes and logistic operations. It is also important to ensure the quality of seasonal raw materials (maize silage, pulp, crop residues) when stored for a long time. For example, it is necessary to avoid the fungal formations in raw material by maintaining the required acidity and water content.

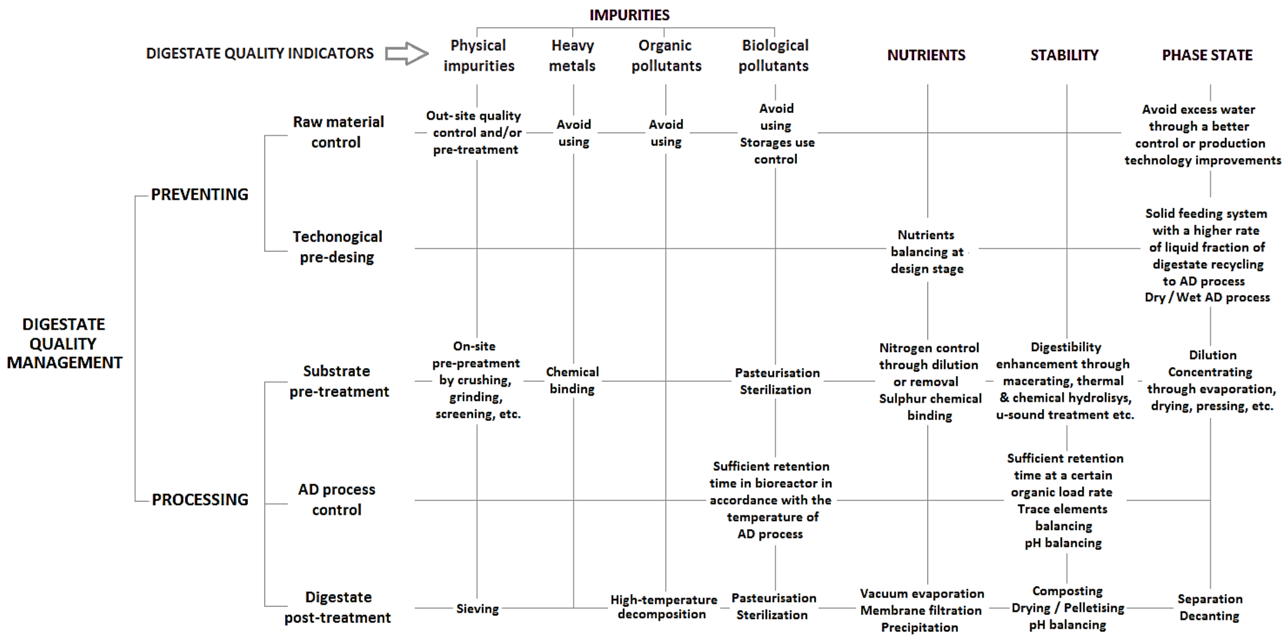


Figure 2 – Digestate quality management matrix

The digestate processing methods include substrate pre-treatment, AD process control, and digestate post-treatment technologies.

Feedstock pre-treatment involves three main methods: pre-sanitation, digestibility enhancement, and solid-liquid separation. In European biogas plants, pre-sanitation usually involves pre-heating specific feedstocks by batch pasteurization at 70°C for 1 hour or pressure sterilization at 133 °C and 2.4 bar (absolute) 20 minutes [3].

In some cases, pre-treatment is also needed where raw feedstock contains physical impurities. It could be processed by simple screening.

AD process control is mostly based on the residence time of the feedstock inside the digester at constant process temperature. Retention times are quoted as hydraulic retention time (HRT), minimum guaranteed retention time (MGRT), and sludge retention time (SRT) to avoid washing out bacteria and colonies. The AD process has a sanitation effect whereby it can inactivate most pathogens in the feedstock mixture inside the digester. Pathogen inactivation/destruction is mainly the result of the combined effect of process temperatures (thermophile or mesophile) and the retention times of feedstock inside the digester. In general, the higher the temperature and the longer the retention time, the higher the pathogen inactivation/destruction effect.

Digestate treatment includes some possible processing steps: solid-liquid separation (SLS), and specific treatments to recover of N, P, K components since N and K mostly follow the liquid fraction (LF) and P follows the solid fraction (SF).

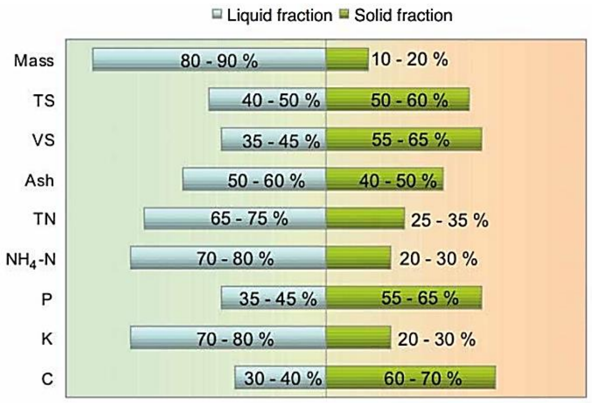
The goal of separation is to separate the digestate into a liquid and solid fraction mechanically. There is no substantial reduction in volume; only the need for storage tanks for liquid digestate is reduced by around 10–20 % by separating the solid fraction, depending on the composition of the starting materials and separation technology. Separation is usually the first step before further processing to obtain concentrated LF and SF suitable for direct and ecologically safe utilization. At least partial process water recycling is recommended, reducing the treatment effort for LF. Specific processing of SF allows to improve its stability and additionally concentrate.

4 Results

Our previous research study showed that centrifugation is one of the most effective solid-liquid separation technologies for digestate to obtain a solid fraction with a high level of dry matter and improve nutrient fractionation between the two fractions [16]. Thus, given the uneven distribution of nutrients in solid and liquid fractions (Figure 3), solid-liquid separation gives the two products with specific functionality [4]. As the leading share of nitrogen is in liquid fraction, there should be attention paid to how to optimally handle it, guarantying preservation of nitrogen, and further the most effective assimilation by plants.

The centrifuge has a very high water-solid separation, especially for digestate with low DM content. However, precipitating/flocculating agents need to be added to improve separation efficiency. The further solid fraction can be dried with or without granulation.

Among the different commercial options for digestate treatment and nutrient recovery, the most relevant for LF are evaporation, struvite precipitation, ammonia stripping, membranes technology, and drying for SF. Digestate pellets production followed by nutrient supplementation/correction may also be considered a commercially viable option.



TS – Total Solids, VS – Volatile Solids, TN – Total Nitrogen

Figure 3 – Distribution of the principal constituents after solid-liquid separation [4]

Drying and evaporation are the suitable methods to reduce digestate volume for SF and LF, respectively. Moreover, drying is an efficient way to use large amounts of waste heat from biogas Combined Heat and Power (CHP). For dried digestate, the desired DM content (up to over 90 %) can be set via drying time and temperature. Since heat is demanded in great quantities for such technologies, heat availability is the crucial factor to consider whether it would be feasible or not. As most biogas plants, especially in Ukraine, produce heat in excess, which is currently not utilized, it could be an option to valorize it through digestate volume reduction. Most frequently, belt dryers are used (Figure 4) in which the digestate is placed on a conveyor belt and dried at temperatures of 60–150 °C for about 2 hours. A similar principle applies to push turn, fluid bed, and drum dryers, in which the digestate is transported through the hot air by the movement of vanes, air injection, or a rotating drum. Hot air is blown through a motionless pile with trailer or container dryers.

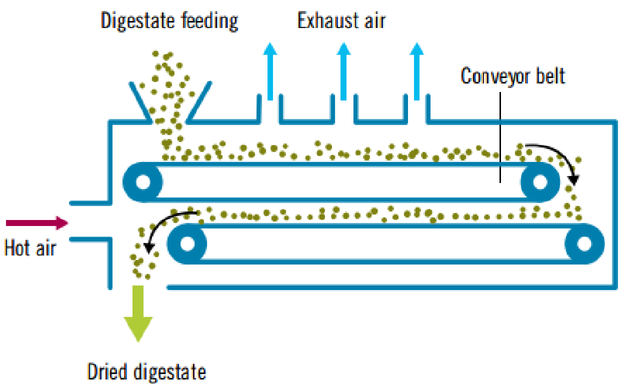


Figure 4 – Belt drier principal scheme [3]

In solar-assisted drying, the digestate is distributed on the floor of a large greenhouse and rearranged by a self-propelled turning trolley. Warm air at around 40 °C is blown onto the digestate layers by fans. Drying is supported by solar radiation into the greenhouse.

Depending on the technology used, the heat requirement is 0.75–1.20 MWt·h of thermally evaporated water per cubic meter (kWh_{th}/m^3 H_2O).

Our previous research [17] indicates the ecological and economic efficiency of energy-saving multi-stage shelf dryers with convective fluidized bed drying, particularly for granular biofertilizer production from the digestate. The developed complex technological process allowed simultaneously achieving several Sustainable Development Goals, including Goals 6, 7, 9, 12, 13, and 15.

Ammonium and phosphate can be removed from the digestate by struvite precipitation (Figure 5), also known as MAP (magnesium ammonia phosphate) precipitation. In order to achieve the best nutrient recovery performance magnesium is added in excess, so that nutrient concentrations are approximately 1.3:1:0.9 for Mg:N:P.

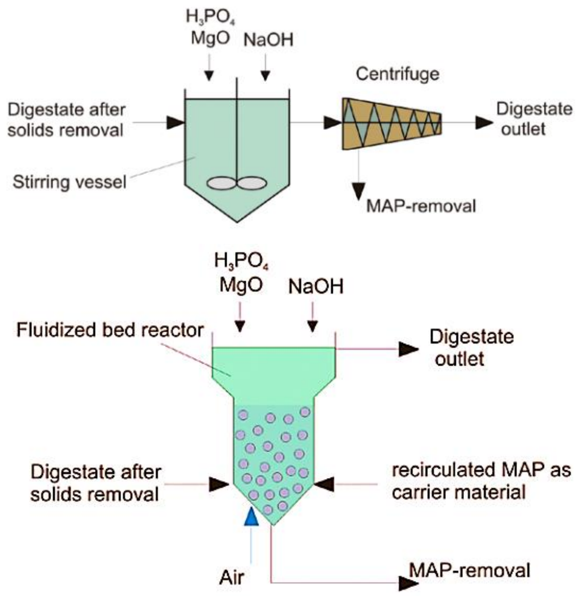


Figure 5 – Possible process options for struvite precipitation [4]

As ammonia is almost always in excess in digestate, magnesium oxide and phosphoric acid are added to the digestate. In addition, pH is slightly decreased to the most favorable for struvite precipitation value at the level of 8.5–9.0 which is in line according to data considered by Silicano et al. in a review [18]. The resulting struvite is a good fertilizer as N, P, and Mg are valuable plant nutrients.

Recovery of nitrogen and phosphorus by precipitation of struvite ($MgNH_4PO_4{\cdot}6H_2O$) can improve N and P management because they may be exported from farms over large distances at relatively low cost. Magnesium-ammonium-phosphate products can contain 12.65 % P in pure compound, while struvite precipitated from organic waste contains from 6 to 12 % [19].

The main disadvantage of struvite precipitation is that a large amount of chemicals is needed, translating into high operational costs. An alternative process can be to recover the chemicals, as struvite releases ammonium and water after heating to well above 100 °C. The resulting magnesium hydrogen phosphate can then be reused for precipitating ammonium and as phosphorus and magnesium source to treat raw wastewater. Researchers studied different decomposition techniques, including struvite pyrogenation, distillation, acidolysis, chlorination, and electrolysis were studied over the last 10 years [18].

Gas stripping is a process whereby volatile substances are removed from a liquid by gas flow through the liquid. In digestate processing, the aim is to recover nitrogen from the liquid in the form of ammonia. The volatility of ammonia in an aqueous solution can be enhanced by increasing the temperature and the pH. So, in digestate processing, excess heat can be used for heating up the digestate, and the pH can be increased by degassing to remove CO_2 or by the addition of alkali. For ammonia stripping in digestate, three main processes are applied: air stripping, vapor stripping, and biogas stripping.

The significant advantage of ammonia stripping is that a standardized, pure nitrogen fertilizer product can be absorbed onto an acidic solution to be recovered and used. In addition, such a fertilizer liquid can enrich other digestate fractions in digestate processing to a standardized nitrogen concentration, which can increase their marketability. This direction must be very topical for further study, moreover, the evidence base for ammonia stripping for recovery of phosphorus and nitrogen from anaerobic digestate was considered too small referred to the outcomes of the recent systematic review [20]. Vacuum evaporation (Figure 6) occurs in a closed system, which means no exhaust air is produced. The liquid digestate is distributed on the inner surface of the evaporator, the internal heat plates, or the heat exchangers. The reduced pressure reduces the boiling temperature to 40–75°C, which means H_2O, CO_2, NH_3 vaporizes. This steam mixture enters a scrubber and is flushed with a countercurrent acidic solution. The condensed product can be recovered.

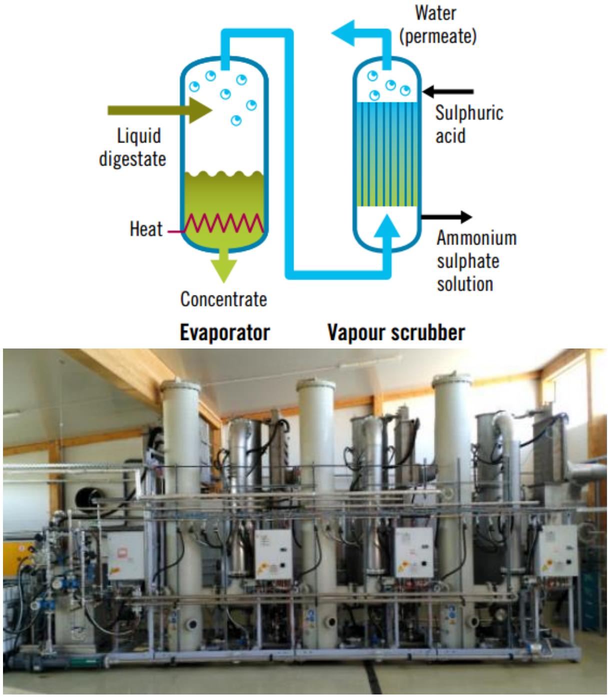


Figure 6 – Vacuum evaporator [3]

Figure 7 – Membrane filtration process with reverse osmosis modules [3]

The performance of the membrane depends on the characteristics of the filtered liquid; therefore, a drawback of such membrane purification processes is that only a limited amount of the digestate will be purified water, and about 50 % of the digestate is accumulated as by-products. The following fractions accumulate in the process: solid fraction, ultrafiltration retentate, reverse osmosis concentrate. The ultrafiltration retentate is often recycled into the biogas plant and/or the solid-liquid separation step to reduce the amounts. Membrane purification is quite expensive and requires a considerable amount of energy with 10–30 kWh_{el}/m^3 input. To improve the process of the digestate membrane filtration optimization could be applied. Basically, it is based on the optimal economic criteria, including the minimal energy consumption for the process performance [21].

The following cases show that evaporation and stripping technologies for digestate processing are used at a commercial scale. From the technological point of view, all the technologies are also applicable in Ukraine. However, it should be proven to be economically feasible and their preconditions exist.

5 Discussion

It is difficult to screen a broad spectrum of chemical pollutants at reasonable costs in practice. For the biogas plant operator, the cheapest and safest way to avoid chemical impurities in digestate is therefore the rigorous selection and quality control of the AD feedstock. Positive lists and feedstock declaration/description are therefore helpful tools, but may only be used only as a guide, and could never substitute the quality control of feedstock materials. Quality control has the determinant role in achieving the required standards of quality for digestate applied as fertilizer and in ensuring the long-term sustainability and safety of this practice.

The main disadvantages of digestate from biogas stations are the variability of its physical and chemical composition and the risks associated with insufficient control of biological safety during its processing, storage, transportation, and application. Thus, without adjustment of the biogas plant operation aimed at creating and controlling the quality of the target product – standard-quality organic fertilizer from digestate for market – the digestate can only be considered as a potential source of valuable elements of organic origin, suitable for compensation of appropriate nutrients from mineral fertilizers. The market quality product must have standardized characteristics, with appropriate techniques for monitoring compliance with such standards.

Accordingly, most countries have strict limits on concentrations of chemical, physical and biological pollutants in any material that is to be applied to land, whilst others place limits on the soil content of such pollutants. National guidelines for impurities in organic residues include maximal values in % DM for total impurities and different fractions such as plastics, metal, glass, iron metals, non-iron metals, stone. Appropriate fertilizer regulations or similar standards was developed and implemented in Austria, Belgium, Finland, France, Germany, Italy, Netherlands, Norway, Spain, Sweden more than 20 years referring to the review by Teglia et al. [22]. Consequently, according to local conditions, Ukrainian legislation can be adopted with European regulations.

Another feature of digestate is the issue of quality and biosecurity control during long-term storage before application. The presence of a certain proportion of unstabilized organic matter and moisture determines the risks associated with the development of undesirable biological processes in the digestate (both solid and liquid fraction), and accordingly changes in the physical and chemical properties, formation of bacterial or fungal nature contamination, etc. Thus, the creation of a market product from digestate is possible only after stabilization, which involves the removal of excess moisture.

The solid fraction of the digestate after the separator has greater potential for market application than the liquid one, consistent with the results of other studies [23, 24]. Thus, in addition to direct use as fertilizer and soil improver, composting with various organic materials for compost production is also possible. Composting is a way to further stabilize and disinfect organic matter, and therefore, in terms of marketing strategies, digestate composting has obvious advantages in terms of long-term quality preservation. The scope of compost covers both the direct use as both organic fertilizer and soil improver and the use of compost as soil substitution in horticulture, greenhouse farming, mushroom cultivation, and domestic and industrial flower growing. In addition, compost is used in general landscaping, technical planning of territories, and landscaping of urban areas. One more potential application could be a digestate or compost for landfills covering or restoring contaminated and/or unproductive land fertility.

The digestate pellets can be optimally marketed in smaller packages in garden centers. The digestate pellets dissolve when exposed to moisture, which means that the nutrients contained are provided to the plant. At present, only a few biogas plants pelletize dried digestate in Europe and subsequently market it outside the agricultural sector, although the potential is estimated to be very high. Digestate pellets can additionally be refined to special fertilizers with mineral or organic additives.

As mentioned above drying of the SF is the main method to concentrate DM and decrease water content to simplify storage and transporting of biofertilizer. Another tip for discussion is the efficiency of applied fertilizer in terms of nutrient content, bioavailability, and nutrient release time. From this point of view, granular fertilizer must be considered a product with high agro-ecological effect and success market demand [25]. One of the advantages of the granular fertilizer from liquid digestate technology is that nutrients from the AD liquor adsorbed onto the solid core material are released more slowly. In addition, granules are easier to handle with crops than small particles. For example, powders tend to be blown away from target sites and are easily washed away. Moreover, the risks associated with handling fine materials, for example, inhalation, are reduced. Granules also have enhanced flow properties when compared to small particles. For instance, small particles have a greater tendency to cake and stick than granular materials. This makes the granular fertilizer easier to apply to a field using mechanical spreaders than powdered fertilizers. A comparison of the physical and chemical properties of whole digestate, separated liquor and fibre and various commercially available fertilizers has indicated that:

− solid fraction of digestate may be suitable for composting with other organic residuals and use on fields;

− liquid fraction of digestate may be suitable for spreading on large surfaces of agricultural fields.

Resuming all the methods of digestate processing, the following digestate-derived products can be obtained as shown in Table 1.

The potential of the organic fertilizer market in Ukraine, including digestate and fertilizers products from digestate is significant with high demand.

The potential of organic fertilizers has traditionally been associated with the introduction of animal and poultry manure. The form of Ukrainian statistical data submission makes it difficult to estimate the actual amount of nutrients coming from manure into the fields and the proportion of such fertilizers from the total volume of their generation. Indirectly, the estimated total potential of nutrients contained in the manure can be estimated by annual generation volume and the specific nutrient content per unit of dry matter.

The volume of the digestate market is related to the development of biogas market in Ukraine. Today, digestate volumes can be estimated at 1.5–2.0 million tons/year. With each additional MW of installed electricity capacity launch based on biogas, an additional 40–50 thousand tons/year of digestate will be generated.

Table 1 – The main types of digestate derived products (DDP)

Digestate derived product	Nutrients	Methods of processing	Energy consumption, kWh_{el}/m^3	Application and market niches
Solid fraction of digestate (SFD)	N – 25–35 % of RD P – 55–65 % of RD K – 20–30 % of RD C – 60–70 % of RD	Solid-liquid separation of RD	0.2–0.6 – SP 2–5 – DC 1.2–5 – BP	Complex organic fertilizer. Soil improver. Co-composting. Soil reclamation. Component for DSFD and DP production.
Liquid fraction of digestate (LFD)	N – 65–75 % of RD P – 35–45 % of RD K – 70–80 % of RD C – 60–70 % of RD	Solid-liquid separation of RD	0.2–0.6 – SP 2–5 – DC 1.2–5 – BP	Fast-released complex organic fertilizer at nearby agriculture lands. Component for DDP production.
Dried solid fraction of digestate (DSFD)	as in SFD (NH_3 reduced via heating)	Drying of SFD	750–1200 kWh_{therm}/m^3 H_2O	Slow-released organic fertilizer. Soil improver. Component for DP production.
Digestate pellets (DP)	as in DSFD	Pelletizing of DSFD	30–50 kWh_{el}/t	Slow-released concentrated organic fertilizer. Energy production.
Ammonium sulphate (AS)	$(NH_4)_2SO_4$	Air/Steam stripping of LFD with H_2SO_4 regeneration	5–10 kWh_{el} + 45–100 kWh_{th}/m^3	Substitution of artificial ammonium sulphate. Chemical industry.
Ammonia water (AW)	$NH_3 \cdot H_2O$ 25–35 % of NH_3	Steam stripping of LFD	5–10 kWh_{el} + 45–100 kWh_{th} per 1 m^3	Substitution of artificial ammonia water. Chemical industry.
Magnesium ammonia phosphate (struvite) (MAP)	$MgNH_4PO_4 \cdot 6H_2O$	Precipitation of permeate after filtration of LFD	10–15 kWh_{el}/m^3	Substitution of N, P fertilizers. Chemical industry.
N-reached MAP (N+MAP)	MAP + AS	Enrichment with AS		Substitution of N, P fertilizers.
Reverse osmosis-concentrate (RO-C)	Complex	Micro–, ultra–, nano–filtration, RO	10–30 kWh_{el}/m^3	Fast-released concentrated organic fertilizer.
Granular fertilizer (GF)	Complex	Adsorbtion in LFD		Slow-released concentrated organic fertilizer.

Notes: RD – raw digestate; RO – reverse osmosis; SP – screw press; DC – decanter centrifuge; BP – belt press

According to the forecasts of BAU [26] for the development of the biogas sector of Ukraine the installed capacity of biogas projects in agriculture can reach 551 MW_e by 2030 what means up to 20 mln tons of digestate generated per year. This is 10-times increase over 10-year period and therefore digestate application should be regulated at the national level.

Quality assurance schemes for compost and digestate products have been established in several EU countries over the past 25 years. Regulation and specifications on digestate management in selected countries (Canada, Sweden France, Germany, and United Kingdom) are clearly described in appropriate Guidelines as considered by Logan and Visvanathan [27]. They form the backbone of sustainable recycling of bioresources, ensuring that quality products are manufactured consistently and placed on the market with high quality. To support the manufacture of quality compost and digestate across Europe, The European Compost Network e.V. (ECN) developed a concept for a pan-European quality assurance scheme (ECN-QAS) within its working group "Quality Assurance and Standardisation". Nevertheless, based on our critical analysis of national standards for compost and digestate concentration thresholds for some pollutants (i.e., HM) are difference for USA (US EPA United States Environmental Protection Agency), UK and Germany (British PAS British Public Available Specification; RAL GZ251 German standards for compost).

In Ukraine, certification of organic fertilizers can be carried out as part of organic production activities. The first Ukrainian certification body to carry out inspection and certification of organic production is LLC "Organic Standard". As a general approach to producing organically means respecting the rules on organic farming. These rules are designed to promote environmental protection, maintain biodiversity, and build consumer trust in organic products. This means that organic producers need to adopt different approaches to maintaining soil fertility including:

− encourage to switch from mineral nitrogen fertilizers to more sustainable alternatives with incentives;

− cultivation of nitrogen fixing plants and other green manure crops to restore the fertility of the soil;

− crop rotation etc.

Ukraine should also regulate reliable professional practice in the application of fertilizers on agricultural land by the requirements for upper application limits, determination of nutrient demand of the plant, nutrient surpluses, blocking periods, and storage capacity for storing organic fertilizers to follow the requirements of the European Nitrates Directive. So, organic production is a complex approach supported among others the use of biofertilizers. Regulations are necessary to consider the requirements and environmentally compatible use of biofertilizers. These can be set at a regional, national, or continental level.

Thus, further research can assess the presence and level in digestate of such contaminants as heavy metals, pesticides and hormones that potentially may enter biogas plants via feedstocks. Also, to evaluate whether other factors influence the overall functioning of BR and on digestate pollutants. Methane potential will also be followed with respect of potential interest in post-digestion. The development of technologies to treat the digestate from biogas reactors is directly related with: a) Prevention of depletion of natural resource, as less minerals need to be extracted and b) Avoiding land degradation, because less natural areas will suffer the impacts of element extraction.

Obtaining biogas from organic waste makes it possible, at a certain level, to talk about achieving the goals of sustainable development: energy – obtaining high-calorie fuel; agrochemical – obtaining environmentally friendly biofertilizers; ecological – utilization of organic waste; financial – reduction of costs for the disposal of organic waste and the purchase of energy; social – the ability to meet social needs on a local scale [28].

Processing biomass by anaerobic fermentation yields two key products: which can be used on agricultural land.

Therefore, the use of digestate as biofertilizers will be a growing factor in achieving high levels of energy independence, environmental security, and financial growth, contributing to sustainable development goals.

6 Conclusions

Anaerobic digestion technology is an essential link in organic recycling in agriculture. Digestate is highly suitable for use as an organic fertilizer or soil improver. The production and recycling of digestate as fertilizer requires quality management and quality control throughout the whole AD cycle from feedstock production until the final utilization of digestate. Quality management based on the life cycle assessment methodology implies using high-quality feedstock, pre-processing of specific feedstock types, close control of the AD process, and process parameters affecting digestate quality, digestate processing, declaration, and optimal storage and application as biofertilizer.

There are two main ways how to manage digestate quality, namely prevention and processing. The rule of thumb is that if efficient pollutant removal cannot be guaranteed either by pre-treatment or through the AD process, the respective material must not be used as feedstock in biogas plants where digestate is used as fertilizer or for other agricultural purposes. Among the different commercial options for digestate treatment and nutrient recovery after solid-liquid separation, evaporation, struvite precipitation, ammonia stripping, and membranes technology are the most relevant for LF, and drying is better for SF.

The potential of nutrient, organic carbon and useful microelements in the digestate of agricultural biogas plants allows its consideration as mineral fertilizer substitution and soil improvement. However, the realization of this potential in an economically feasible way requires the development of both methods of preparation and quality control of digestate products and the market of organic fertilizers and soil improvers in Ukraine.

Application and market niches of the main types of digestate derived products were offered as well as methods of their processing. Like other European countries, Ukraine should develop and implement its own rules to specify requirements for organic fertilizer constitution, e.g., what substances can be used, limit values on heavy metals and other pollutants, relevant nutrient contents, and requirements on labeling and marketing.

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