AGRICULTURAL FERTILIZERS OBTAINED FROM INDUSTRIAL WASTEWATER SLUDGES, AN ALTERNATIVE OF CIRCULAR ECONOMY FOR ENVIRONMENTAL PROTECTION

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REZUMAT. La nivel mondial, există o preocupare intensă pentru recuperarea deșeurilor industriale. Procesul de tratare a apelor uzate generează nămol, care afectează negativ sănătatea și economia. Utilizarea nămolului ca îngrășământ pentru agricultură este una dintre cele mai durabile soluții atunci când este în conformitate cu toate condițiile impuse de legislație, îmbunătățind fertilitatea solurilor și contribuind la o dezvoltare durabilă a mediului. Lucrarea prezintă rezultatele experimentale pentru obținerea îngrășămintelor agricole folosind un bioreactor special conceput în care componentele sunt amestecate urmând ciclul: materie primă (sol) + deșeuri (nămol din apă uzată, compost) → producție → produs (amestec - îngrășământ agricol) → reciclare → deșeuri + materie primă ..., concept al economiei circulare. În cele din urmă, sunt prezentați indicatorii calitativi și energetici ai rezultatelor obținute, corelate și raportate la legislația privind protecția mediului.

Cuvinte cheie: îngrășământ, bioreactor, agricultură, nămol din apă uzată, sol, economie circulară

ABSTRACT. There is an intense concern worldwide for the recovery of industrial waste. The wastewater treatment process generates the sludge which negatively impacts the health and the economy. The use of sludge as fertilizer for agriculture is one of the most durable solution when it is in compliance with all the conditions imposed by the legislation, improving the fertility of soils and contributing to a sustainable development of the environment. The paper presents the experimental results for obtaining agriculture fertilizers using a special designed bioreactor in which components are mixed following the cycle: raw material (soil) + waste (wastewater sludge, compost)→ production → product (mixture - agriculture fertilizer) → recycling → waste + raw materials ..., that means the concept of circular economy. Finally, are presented the qualitative and energy indicators of the obtained results, correlated and related to the environmental protection legislation.

Key words: fertilizer, bioreactor, agriculture, wastewater sludge, soil, circular economy

INTRODUCTION

The advancement of technology during the last decades and its application in almost all economic sectors contributed to the development of the society and to a higher standard of life. However, economic development and population growth have led to over-exploitation of resources and to the generation of large amounts of waste (207 million tons of waste generated in EU). According to Eurostat statistics, even if, between 2004 and 2018 waste generation in the EU-27 followed different patterns, it was found that the waste (waste and water services) increased by 175.7%.

This situation implies not only the depletion of resources, but also an increase in environmental pollution, requiring a change of attitude in respect of consumption of resources and waste management.

The modern approach regarding wastewater treatment sludges is focused on the recovery of the nutrients (especially Nitrogen, Phosphorus, Potassium, Natrium, non-toxic metals) which can represent an agronomic benefit. The use of industrial sludges in agriculture, directly or after treatment, is the most efficient and durable solution to fertilize the soil with effects on the reduction of costs and environmental protection (Guerra-Rodríguez S. et al., 2020). In fact, in 2018, the highest level of the EU-27 waste was generated from economic activity (except for major mineral waste).

Considering all the figures, researches in the field must continue to offer more possibilities for sludge recovering from treatment plants by capitalizing it in ecological products in order to reduce pollution and resource depletion. Thus, the need for better waste management should consider first the possibilities of their recovery and, ultimately, their disposal and elimination.

Therefore, the paper presents a solution that can recover wastewater sludges from textile industry and from urban water treatment plants (as compost), in compliance with the principles of the bioeconomy. Within experimental researches there were mixed in certain proportions inside a specially designed bioreactor, the components: raw material (soil) + waste (wastewater sludge, compost) and was obtained the product (mixture - agriculture fertilizer). The qualitative and energy indicators of the resulting product comply with the provisions in force regarding environmental protection. Furthermore, after using the mixture as a fertilizer on agricultural land, the soil can be reintegrated into the circular system of resource conservation.

1. LITERATURE REVIEW

First Circular Economy Action Plan was adopted by the European Commission in December 2015 and was focused on reducing, recycling, and recovering of waste, mainly for paper, ferrous metals, aluminium, glass, plastic, and wood. The new Circular Economy Action Plan adopted in March 2020 is more comprehensive and presents measures for the sectors that use most resources while having a high potential for circularity, among which is „Food, water and nutrients".

Considering the fast increase of the waste volume generated both by industrial wastewater treatment plants and municipal wastewaters plants, the member states of the EU are obliged to implement and respect more regulations, such as (Przydatek G., 2020):

– Directive 86/278/EW of 12 June 1986 stipulates that the use of sludge in agriculture is prohibited if the concentration of heavy metals exceeds certain limit values.

– Directive 91/271/EEC, adopted on 21 May 1991, concerns the treatment of municipal sewage and is the operational directive.

– Directive 99/31/EC of 26 April 1999 is referring to the limits for storing sewage sludge and is also called the Landfill Directive.

– Directive 2000/60/EC of the European Parliament and Council of Europe sets the norms of joint community action in the field of water policy. The Water Framework Directive defines sludge not as waste material, but as a "product" of sewage treatment.

– Directive 2008/98/EC about waste is the Waste Framework Directive that regulates recycling of wastes, including sewage sludge.

There are several tools and measures that can be used to save or help recycle nutrients. The proper solution is chosen depending on the context in which the technology is applied and on local circumstances (Rosemarin A., et al., 2020).

The implementation of these measures contributed to the change in sludge characteristics and increased soil fertility parameters, including total organic carbon, available soil nitrogen, available soil phosphorus and available soil potassium to 0-15 cm depth (Arif M. S., et al., 2018).

The use of raw or treated industrial sludge in agriculture reduce the costs for sludge removal from wastewater treatment plants, as well as much of the requirements for inorganic components (nitrogen, phosphorus) on agricultural lands (Caritá R., et al., 2019).

Controlled application of industrial sludge on lands maximize benefits with minimal impact being considered a simple and economical solution for soil fertilization (Ahmad T., et al., 2016).

Recognizing sludge as a resource, not as a waste, brings in researchers attention the possibility to recover valuable components from sludge in order to create new products as an alternative of circular economy for environmental protection (Gherghel A., et al 2019).

2. SLUDGE RECOVERY FROM TEXTILE WASTEWATER TREATMENT PLANTS FOR REUSING AS FERTILIZER IN AGRICULTURE

The main objective of the experiments is to obtain fertilizer for agriculture from textile sludges and compost using a specially designed bioreactor and a specific methodology. The obtained products are tested in order to determine the qualitative and energetic indicators and to verify the compliance with the legislation in force.

2.1. Materials used in experiments

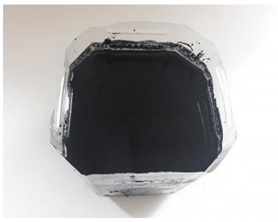
Materials (Fig. 1) used to perform the experiments are:

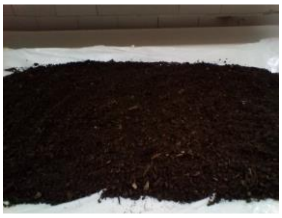
a) waste: sludge from the textile wastewater treatment plant in non-centrifuged form;

b) waste: compost;

c) raw material: agricultural land cleaned by any hard components (stones);

d) a bioreactor specially designed and realized by the authors within the research project no. 248/2018.


Wastewater sludge


Compost


Soil


Bioreactor

Fig. 1. Materials used in experiments to obtain the agriculture fertilizer.

2.2. METHODOLOGY FOR OBTAINING THE MIXTURE/ FERTILIZER FOR AGRICULTURE

Preparation of the bioreactor for operation and check before starting the operation process:

- Powering the biorector with the components of the mixture:

– the sludge is used in non-centrifuged form;

– the soil used is separated from any hard components (stones) by sieving;

– portion the components of the mixture: Sludge - 2 parts (10 kg) - 50% of the mixture; Compost - 1 part (5 kg) - 25% of the mixture; Soil - 1 part (5 kg) - 25% of the mixture - in 3-4 batches;

– start the bioreactor engine;

– bring the bioreactor to the operating parameters;

– open the bioreactor cover by lifting the cover window;

– the mixture of sludge + compost + soil is introduced, in the established proportion;

– close the lid window;

– stir the mixture;

– repeat the feeding operation, with another mixing batch, by opening the window of the bioreactor cover;

– continue stirring the mixture;

– the development of the mixing process is observed through the lid window;

– when the mixture is obtained, stop mixing;

– the whole mixing process must take 60 minutes;

– stops the bioreactor engine;

– the mains supply is switched off;

– the operation process is continued with the evacuation of the mixture from the bioreactor, in special vessels so that it can be sent to the laboratory to perform the analyzes;

– strictly follow the order and procedures recommended for use and maintenance;

– only trained personnel are allowed to use and clean the bioreactor.

- Procedures for discharging the mixture from the bioreactor:

– after finishing the mixing operation and obtaining the final mixing composition, the engine is stopped and the prototype of the biorector from the electrical network is disconnected;

– open the bioreactor outlet, located at the bottom;

– connect the bioreactor to the mains and start the engine. The movement of the coils ensures the evacuation of the mixture in specially prepared vessels;

– the removal of the mixture is performed at a frequency of the motor supply voltage of 30 Hz and the output speed of the worm wheel: 28 -29 rpm;

– stop the engine again;

– disconnects from the mains;

– continue evacuating the mixture from the bioreactor, manually.

- Bioreactor cleaning and washing procedures:

– after evacuating the mixture from the bioreactor, the bioreactor is washed with water jet from the network;

– the washing water is discharged, through the drainage pipe, in the sewerage network of the wastewater treatment plant.

2.3. IDENTIFICATION AND DETERMINATION OF QUALITATIVE INDICATORS UNDER OPERATING CONDITIONS OF THE BIOREACTOR

In Table 1 are presented the main results obtained during the laboratory experiments referring to the quality indicators of the obtained agriculture fertilizer.

Considering the methodology and the operating characteristics of the bioreactor, it can be concluded that the variables of the working process are:

– proportion of components in the mixture;

– how to add the components: one by one (portioned);

– time for adding the components and forming the mixture: 60 minutes;

– operating frequency (speed) of the bioreactor prototype: 50 Hz;

From all the experimental tests performed, 3 tests were selected for which the best results were obtained in terms of homogeneity, physical appearance and physico-chemical characteristics (table 2).

Table 1. **Interpretation of experimental test results for quality indicators according to environmental legislation and literature**

Test	**Humidity** [%]	**pH** [unit pH]	**Humus** [mg/kg. dry substance]	**Organic carbon** [mg/kg. dry substance]	**Total nitrogen** [mg/kg. dry substance]	**C/N**	**Heavy metals** [mg/kg. dry substance]									**Total phosphorus** [mg/kg. dry substance]	**Potassium** [mg/kg. dry substance]	**Magnesium** [mg/kg dry substance]
							As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn			
No. 1	59.32	low alkaline	129645 alkalin	89227.6 alkaline	3433.1 alkaline	25,99	<1.0	<3.0	19.6	4.68	<0.01	34.46	4.58	26.56	43.66	23.86 good value	76.92 good value	68.68 high value
							Values that respect the limits imposed by the environmental legislation											
No. 2	72.86	low alkaline	129762.4 alkaline	85794.6 alkaline	2920.16 alkaline	29,38	<1.0	<3.0	16.92	4.61	<0.01	29.76	3.9	25.65	40.96	24.11 good value	71.78 good value	62.0 high value
							Values that respect the limits imposed by the environmental legislation											
No. 3	52.14	low alkaline	164724.0 alkaline	108398.0 alkaline	4294.0 alkaline	25,24	<1.0	<3.0	24.6	4.9	<0.01	43.2	5.73	28.8	49.4	28.9 good value	88.0 good value	78.9 good value
							Values that respect the limits imposed by the environmental legislation											

2.4. Identification and determination of energy indicators under operating conditions of the bioreactor

The determination of energy efficiency indicators was performed in accordance with the experimental methodology by taking into account the following parameters that influence them:

- Amount of mixed components;
- Mixing time;
- Final blend features;
- Technical characteristics of the worm gear reducer:

– rated power: P = 0.37 kW;
– moment of exit from the reducer: M = 49 Nm;
– output speed: 47 rpm;
– max frequency: 50 Hz;
– transmission ratio: i = 60.

- Technical characteristics of the electric motor 56 B5:

– type: single-phase asynchronous;
– rated voltage: 230 V, 50Hz;
– speed: 3000 rpm.

- Operations performed according to the bioreactor operation manual: time and frequency of the supply voltage:

– feeding and mixing;
– frequency of motor supply voltage 50 Hz; output speed - 47 rpm;
– operation time - 60 minutes;
– discharge of the mixture from the bioreactor:
– frequency of motor supply voltage: 30 Hz
– output speed of the worm wheel: 28 -29 rpm; for 20 minutes;
– manual evacuation of the mixture from the bioreactor: time 20 minutes;
– cleaning and washing the bioreactor: for 30 minutes.

2.5. Discussion

Analyzing the results presented in Table 1, it is found that:

– the increase of the percentage of compost and soil in the composition of the bioreactor mixture results in the increase of the values corresponding to the indicators humus, organic carbon and total nitrogen;

– the increase of the percentage of sludge in the composition of the bioreactor mixture results in the decrease of the values corresponding to the indicators, organic carbon and total nitrogen and humus;

– the increase of the sludge percentage in the composition of the bioreactor mixture results in the increase of the values corresponding to the humidity indicator;

– the increase of the resulting sludge in the textile wastewater treatment plant, in the composition of the bioreactor mixture results in the increase of the values corresponding to heavy metals, without exceeding the limits imposed by environmental legislation and legislation on the use of sludge in agriculture.

Table 2. **Correlation of quality indicators and energy indicators**

Experimental test	**Quantity of mixed components**						**Features of fertilizer**	**Operation**	**Time [min]**	**Working frequency [Hz]**	**Energy consumption [kW]**	**Specific energy consumption [kW/kg]**
	Sludge		**Soil**		**Compost**							
	[%]	**[kg]**	[%]	**[kg]**	[%]	**[kg]**						
No. 1	60	12	20	4	20	4	Composition - complies with environmental legislation on the application of sludge to soil and soil treated with sludge Density - 1.41 Appearance - Wet, gray paste with fine agglomerations For the 10 cm layer to be applied on the ground, the conditions imposed by Order 756/97 "Regulations on the assessment of environmental pollution" and by Order 344/2004 "Technical norms on the protection of the environment and especially of soils, when using sludge" are met. treatment in agriculture "	feeding and mixing	60	max. 50	0.74	0.037
								mixture evacuation by engine operation	20	max. 30	0.13	0.0065
								manual evacuation of the mixture	20	-	-	-
								jet washing of mains water	30	-	-	-
								TOTAL	130	-	0.87	0.0435
No. 2	66	16	17	4	17	4	Composition - complies with environmental legislation on the application of sludge to soil and soil treated with sludge Density -1.32 Appearance - Wet, gray paste with medium agglomerations For the 10 cm layer to be applied on the ground, the conditions imposed by Order 756/97 "Regulations on the assessment of environmental pollution" and by Order 344/2004 "Technical norms on the protection of the environment and especially of soils, when using sludge" are met. treatment in agriculture "	feeding and mixing	60	max. 50	0.74	0.0308
								mixture evacuation by engine operation	20	max. 30	0.13	0.0054
								manual evacuation of the mixture	20	-	-	-
								jet washing of mains water	30	-	-	-
								TOTAL	130	–	0.87	0.0362
No. 3	50	10	25	5	25	5	Composition - complies with environmental legislation on the application of sludge to soil and soil treated with sludge Density - 1.39 Appearance - Wet, gray paste with fine agglomerations For the 10 cm layer to be applied on the ground, the conditions imposed by Order 756/97 "Regulations on the assessment of environmental pollution" and by Order 344/2004 "Technical norms on the protection of the environment and especially of soils, when using sludge" are met. treatment in agriculture "	feeding and mixing	60	max. 50	0.74	0.037
								mixture evacuation by engine operation	20	max. 30	0.13	0.0065
								manual evacuation of the mixture	20	-	-	-
								jet washing of mains water	30	-	-	-
								TOTAL	130	–	0.87	0.0435

The results obtained for the three variants of the mixture composition, experimented on the bioreactor, confirm the possibility of using this mixture, with a composition varying: (50 - 66)% sludge, (17 - 25)% soil, (17 - 25)% compost, for use in agriculture. All three variants of the composition of the mixture ensure compliance with the conditions imposed by the relevant legislation on sludge used in agriculture.

According to the results in Table 2, the following are found:

- energy indicators (specific energy consumption) decrease with increasing amount of sludge processed per batch: 0.0362 kW/kg mixture - 0.0435 kW/kg mixture;
- the constant maintenance of the obtained mixture mass results in the same energy consumption and the same specific energy consumption; (Tests no. 1 and no. 3);
- the variation of the percentage of components in the mixture influences its appearance and density in the conditions in which the maximum working frequency of 50 Hz and mixing time 60 minutes is used;
- the evacuation and washing operations of the bioreactor prototype have an insignificant contribution to the value of the energy index (energy consumption and specific energy consumption);
- the 3 experimental tests were selected both because they have the best results as an aspect of the mixing test but also because they meet the conditions imposed by environmental legislation on soils and the use of sludge in agriculture;
- between the 3 examples of experienced mixtures, one of the variants can be used, depending on the nature of the soil on which the mixture will be deposited (physico-chemical characteristics).

CONCLUSIONS

High quality sludge without contaminants contains valuable nutrients that can be recycled as fertiliser for agricultural lands. The approach to the use the wastewater sludge in agriculture has economic effects and contributese to environmental protection. The team of authors developed and tested using a new bioreactor an innovative mixture that uses waste (sludge and compost) for further utilization in agriculture. The tests for determining the qualitative and energy indicators, concluded that they are in complience with all the conditions imposed by the existing legislation.

In conclusion, the new fertilizer obtained from wastewater sludge represents an alternative of circular economy for environmental protection.

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