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# Recycling of Municipal Sewage Sludge in Sustainable Logistics Systems in the Focus of Information Technology Management

**Olena Chukurna ***

*Corresponding Author, Department of Marketing, Odessa Polytechnic State University, Odessa, Ukraine. Email: elenachukurna@gmail.com

**Vladyslav Vaysman**

Department of Design Information Technology at Mechanical Engineering, Odessa Polytechnic State University, Odessa, Ukraine. E-mail: vaysman@micron.ua

**Oleg Kassien**

Earth Revival Technologies Ltd., Stabu st., 57B-23, Riga, Latvia, LV-1011. E-mail: oleg.kassien@earth-revival.com

**Vitalii Dobrovoslkyi**

Department of Marketing, Odessa Polytechnic State University, Odessa, Ukraine. E-mail: dobrovit05@gmail.com

**Natalia Strunnikova**

Earth Revival Ltd., Maskavas st., 57-3, Riga, Latvia, LV-1003. E-mail: natalya.strunnikova@earth-revival

## Abstract

The article is devoted to the problem of designing recycling in sustainable logistics systems in the field of processing wastewater treatment waste - municipal sewage sludge (MSS) **in the focus of information technology management.** The essence of the developed and proposed wastewater treatment project is based on its integration into the city's public utilities system, which will be a single basis for a closed-type logistics system that is managed on the basis of the introduction of a unified information system. This approach to the design of sustainable logistics systems ensures the formation of a closed material and informational logistics flow according to the "supply of raw materials - production - product distribution". This allows solving two problems: ensuring the creation of a closed logistics system that is managed by a single information base and developing a new type of fertilizer.

The solutions proposed in this project in the implementation of the MSS processing project are complex and allow implementing all areas of the sustainable development strategy in the aspect of implementing modern information systems. The design technology makes it

possible to completely close the logistics cycle for the supply and processing of MSS into finished products in the form of organic fertilizers.

**Keywords:** Information Technology Management, Sustainable Logistics System, Information Systems, Informational Logistics Flow, Recycling, Municipal Sewage Sludge, Organic Fertilizers.

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## Introduction

In the context of the implementation of the sustainable development strategy, the issues of creating adaptive logistic systems of a closed type, which are based on ensuring waste-free production, including from the results of human economic activity, are especially relevant. An important feature of which is integration into managed information technologies.

The design of environmentally sustainable logistics systems integrated with information technologies, focused on solving the problems of recycling in the context of the implementation of the "Clean City" concept is becoming a global challenge. Global trends in the design and implementation of environmentally sustainable logistics systems are aimed at creating recycling in the field of processing household waste in the focus of information technology management. The increase in population and consumption volumes, in turn, contribute to an increase in the number of manufactured packaging, household waste and human waste. At the same time, insufficient attention is paid to the problems of MSS processing and the creation of environmentally sustainable closed-cycle logistics systems in the focus of information technology management in scientific publications and developments.

The formation of domestic waste water in the territory of settlements is one of the most significant factors of negative impact on the environment. Complete biological treatment of urban wastewater, which is widely used today, is accompanied by the formation of significant amounts of sludge. After fermentation and mechanical dewatering, the sludge is in most cases stored in special sludge areas. Such disposal of sludge leads not only to significant consumption of land resources, but also to an increase in soil and groundwater pollution with toxic components that make up the sediment (Tsybina A.; 2018).

A rational system for water disposal and treatment of industrial, surface and domestic wastewater, which is integrated by a single information base is a necessary element of the life support of every modern city, implemented in the context of sustainable development goals. This is possible through the design of sustainable logistics systems based on the management of a single information system. The technological schemes of wastewater treatment operating in different countries have a similar structure, however, the methods of disposal of waste generated in the process of water treatment are very diverse. Under these conditions, there is a need for wastewater treatment logistics systems based on recycling.

## Literature Review

The methodological basis of the research is mainly composed of the works of foreign and domestic researchers in this field.

The most of scientists interpret sustainable logistics systems as taking into account ways to reduce the factors of their influence on the environment and ecology. In this context, most of the studies on sustainable logistics systems have been implemented.

Vitor W.B. Martins, Rosley Anholon, Osvaldo L.G. Quelhas and Walter Leal Filho understand sustainable logistics systems, precisely such systems that include the analysis and promotion of sustainable procurement, sustainable transportation, sustainable packaging, ecological distribution, recycling, design and control of green supply chains (Vitor W.B. Martins, Rosley Anholon, Osvaldo L.G. Quelhas, Walter Leal Filho; 2019).

Researchers such as Wang D.-F., Dong Q.-L., Peng Z.-M., Khan S., and Tarasov A. understood as a sustainable logistics system, a system aimed at reducing the impact of logistics operations on the environment (Wang D.-F., Dong Q.-L., Peng Z.-M., Khan S., Tarasov A.; 2018).

Reefke H. and Lo J.A. interpret sustainable logistics in supply chains in the context of implementing approaches to green supply chains (Reefke H.; Lo J.A; 2015).

The most of the scientific research in this context is devoted to green logistics issues (Gryshchenko et al., 2022; Timoshenkov et al., 2020). However, at present there is no unified approach to defining the concept of a sustainable logistics system in the concept of environmental logistics. The concept of ecological or green logistics is often viewed as an integrated approach to logistics and socio-economic activities.

Such scientists as Bazaluk et al (Bazaluk et al; 2020) were investigated the problem of circular economy, part of which is environmental logistics. Scientists have proven that the reduction of CO2 emissions is facilitated by an alternative energy source, namely the use of green methanol. The possibility of potential methanol production using recycled waste and wind energy is proved.

Rudenko, S., Gogunskii, V., Kovtun, T., Smrkovska, V. (Rudenko, S., Gogunskii, V., Kovtun, T., Smrkovska, V.; 2021) substantiated methods for assessing the effectiveness of an environmental project under the influence of transformational changes. The authors focus on project management decisions in approaches to assessing the effectiveness of environmental projects, without considering them as sustainable systems.

The scientific approach to sustainable systems management proposed by Latysheva, O., Rovenska, V., Smyrnova, I., Nitsenko V., Balezentis, T., Streimikiene, D. (Latysheva, O., Rovenska, V., Smyrnova, I., Nitsenko V., Balezentis, T., Streimikiene, D.; 2020) provides an industry-specific approach in the field of mechanical engineering. At the same time, the focus of the research is aimed at the implementation of the spatial approach.

The spatial approach in the implementation of logistics goals is also used by Kurbatova S. M., Aisner L. Yu. and Mazurov V. Yu. (Kurbatova S. M., Aisner L. Yu., Mazurov V. Yu.; 2020 ). The authors consider logistics and transport as an element of a strategy for sustainable development of territories.

A systematic approach to the development of the territory based on the introduction of urban underground logistics is substantiated by Chinese scientists Lu B., Zhang M. X. and Fan Y. Q. (Lu B., Zhang M. X., Fan Y. Q.; 2021)

All the authors' studies in the field of sustainable logistics systems based on recycling are noteworthy and scientifically substantiated.

At the same time, in scientific publications, much attention is paid to traditional transport systems in the field of logistics (Babenko, 2019).

Considering the global trends in the development of a closed-cycle economy, within which a special place is given to recycling in the field of optimization and processing of wastewater sludge, it becomes necessary to study scientific approaches in this area.

In this context, the research of Chinese scientists in this area deserves attention. The authors of the study Qian Zeng, Nvzhi Tang, Hui Chen, Rui Xiao and Jinghui Gong reflect the results of studies of the bacterial and chemical composition of effluents and sludge from industrial waste, proving the need for their purification (Qian Zeng, Nvzhi Tang, Hui Chen, Rui Xiao, Jinghui Gong; 2020). However, they do not provide for an integrated and integrated approach to solving this problem within the framework of the recycling program

## Data and Methdology

The following methods were used in the research work: the method of project analysis - when calculating the technical and economic profile of the project; method of economic analysis - in the formation of methodological approaches to the calculation of project performance indicators; technical design methods - when calculating the technical performance of the units; methods of comparative analysis - when comparing the technical capabilities of various methods of processing and purifying wastewater, as well as when comparing various fertilizers.

## Results and Discussion

Currently, there are various systems and technologies for the disposal and processing of MSS. The placement of MSS in the environment is the oldest and most widespread method of removing MSS from the technological process of domestic wastewater treatment. There are various placement technologies - discharge into water bodies, burial, drying, storage, storage of sediments in sludge areas. These are the cheapest and easiest ways to remove MSS from the technological process (Table 1).

For the implementation of existing methods of wastewater sludge processing, dehydration is primarily carried out, due to the high humidity of these wastes. Dehydration is carried out in several stages using various units. First of all, sediments are thickened in sedimentation tanks, and then mechanical dehydration, using vacuum filters, centrifuges, filter presses and other devices for this. In some European countries, for example in Germany, liquid MSS can be used in agriculture without dehydration. At the same time, in order to protect groundwater from pollution, the amount of sediment introduced into the soil is strictly controlled. In Norway and the Netherlands, before being applied to the soil as fertilizer, MSS is treated by drying and granulation.

After mechanical dehydration, it is rational to carry out thermal drying of the sludge. It allows not only to reduce the amount of MSS, but also to carry out its disinfection. Thermal drying is widely used in such European countries as Denmark, Germany, Finland.

However, the main disadvantages of all these methods of MSS placement technology are:

- negative impact of MSS on environmental objects, pollution of surface and ground waters, air, soil;
- loss of valuable raw materials that can be used to obtain organic fertilizers and recultivate disturbed lands;
- for the disposal of MSS (except for the method of discharge into water bodies), it is required to allocate significant areas, withdraw them from economic activities for a long time;
- the high cost of maintaining and expanding the MSS placement infrastructure, and during incineration - also extremely high operating costs.

Waste disposal can be done in the following ways:

1) MSS can be used as additives in the production of materials for road construction, ash production in the combustion process, which is used in the production of building materials. When carrying out low-temperature pyrolysis from MSS, so-called "crude oil" is obtained.

The advantages of these thermal methods of MSS utilization are a significant reduction in the volume and weight of utilized waste and minimization of its negative impact on the environment (Iticescu, C.; Georgescu, P.-L.; Arseni, M.; Rosu, A.; Timofti, M.; Carp, G.; Cioca, L.-I.; 2021). The main problem arising during the incineration of sludge is the formation of combustion products containing toxic compounds, as well as a certain amount of ash containing heavy metals and other toxic substances. This problem is solved by the use of systems for filtering the exhaust gases of combustion (Sokiran M.; 2019).

2) One of the directions for the treatment of urban wastewater sludge is the use of the energy potential of sewage sludge, namely, the utilization of biogas formed during sludge digestion.

So, in Poland in Szczecin, at the station Zaklad Wodociągow i Kanalizacji Sp z.o.o. w Szczecinie ZWiK MSS is subjected to mesophilic fermentation at 37 °C for one month. The resulting biogas is used at a high-performance CHP to generate electricity, which is enough both for the operation of the CHP itself and for meeting the electricity needs of the treatment facilities (Tsybina A.;2018).

The disadvantages of the above methods are:

- high cost of the equipment;
- high energy consumption of the processes used;
- negative impact of these processes on the environment;

3) Agricultural use. MSS can be used to obtain fodder protein and feed additives, compost and vermicompost. The production of feed protein and feed additives occurs under the influence of special microorganisms. This process has not found wide application due to its specificity. Receiving compost and vermicompost requires placing MSS on large specially equipped areas, maintaining a constant temperature in the processed mass for a long time (3-6 months). Which is difficult in regions with a pronounced seasonality and with long periods of the cold season.

In all cases of subsequent disposal with the use of various wastewater treatment technologies, the main stage is to improve the sanitary safety of MSS for their further use. At the same time, preliminary disinfection of MSS can be carried out in the following ways:

- Microbial transformation of organics is applied mainly to manure and dung.
- Chemical neutralization of pathogens: usually alkaline, depends on the further use of the treated MSS (the dose of the reagent reaches 300–400 kg per ton of dry matter; to prevent ammonia emissions into the atmosphere, it may be necessary to wash the sludge with an acidic solution).
- Disinfection on special surfaces using solar energy.
- Neutralization of pathogens by ionizing radiation.

These methods also require the cost of using chemicals, radiation sources, large areas (for disinfection on surfaces).

Almost all existing technologies and wastewater treatment systems, accompanied by the formation of sludge, are not closed-loop systems, with the exception of those that include the production of fertilizers from MSS. Moreover, all of these processing methods are not logistic systems.

Table 1. Existing technologies and systems of waste water placement and treatment (Valetov D. S., Kashchenko O. V.; 2018).

| Method | Restrictions on application depending on the composition of MSS | Economic costs of implementation | Obtaining Useful Products | Environmental impacts from implementation | Quantity of secondary waste | Recycling of secondary waste |
|---|---|---|---|---|---|---|
| Burning | No | High dewatering and flue gas cleaning costs | No | Reduction of waste weight by 60-70% (per dry substance). Pollution by air emissions, including dioxins | 30-35% of waste mass (ash containing toxic elements) | Possibility of ash use in road construction |
| Pyrolysis (thermal destruction) | Increased requirements for fire and explosion safety | Averages | Pyrolysis gas (for thermal energy) | Reduction of waste mass by 60-70% (per dry substance) | From 50% of the weight of WWS. Solid pyrolysis products containing toxic elements | Possibility of use in road construction |
| Fertilizer production | Compliance with the requirements of regulatory documents for the use of WWS as fertilizers and for soil preparation | Poor | Fertilizer for a wide range of crops depending on composition | Minimum (subject to relevant standards) | no | Not required |
| Soil production | | Poor | Soil | Minimum (subject to relevant standards) | no | Not required |

The idea of the author's approach is that wastewater treatment should be integrated into the city's communal services and provide a unified closed-loop recycling system. Thus, the system for the supply of wastewater to the place of their further processing will be closed, and the purification process will end with the receipt of the final product used as fertilizer. In turn, the outgoing material flow in the form of a finished product (fertilizer) should be formed taking into account the supply chains of organic fertilizers. Thus, this approach allows us to solve two problems: it ensures the creation of a closed logistics system and the development of a new type of fertilizer.

The author's approach is due to the need to solve the problem of the irrationality of traditional methods of MSS handling, combined with a high load on the environment and the search for alternative ways of MSS processing. A rational solution to the problem of MSS utilization and stopping the accumulation of waste volumes, soil restoration lies in an integrated approach to the return of MSS to agricultural use.

The author's approach is based on the technological solutions of the Earth Revival company, which is a combination of methods that is flexible enough to adapt in any region, at any level of urbanization and with any, even minimally developed logistics infrastructure. An obligatory condition for the implementation of this approach is the formation of an information technology management system at the enterprise, which makes it possible to coordinate material and information logistics flows.

This technology replaces and greatly accelerates the traditional composting process. Allows in a continuous mode, in 4-6 days, economically and excluding harm to health and the environment, to process MSS into high-quality organic fertilizer. Retains all the positive aspects of the natural process, while eliminating the risk of infection by pests and weeds. Reduces the level of metals and their mobile forms. Destroys pathogenic microflora.

The economic feasibility of this technology consists of a combination of three main sources of income:

- sale of equipment "Earth Revival", which is easily integrated with existing wastewater treatment systems in the municipal infrastructure of the city;
- elimination of the need to store waste and, as a consequence, the elimination of the construction of specially equipped landfills and the saving of funds aimed at waste disposal;
- stabilization (neutralization of pathogens) and processing of MSS into a valuable product - fertilizer;
- application of the produced basic organic fertilizer or a line of complex organic and organo-mineral fertilizers to restore and maintain soil fertility.

All these three stages are taken into account in the technological design of the MSS processing system, which ensures complete recycling.

The developed recycling technology in the context of its implementation as applied to each region may depend on the priority of each stage. This approach enables the design of flexible systems that take into account all the elements that ensure environmental sustainability. At the same time, it includes a logistic approach to building supply chains for raw materials and finished products, while observing recycling technology. Thus, this project approach allows solving the problems of creating environmentally sustainable logistics systems. The implementation of the project and its integration into the urban system depends on the following factors:

- the possibility of implementation and the cost of various approaches to waste disposal;

- the peculiarities of the legal regulation of a country or region, as well as social factors;
- availability of free areas for storing MSS or the possibility of discharge into water bodies;
- the economic costs required for the disposal of MSS, the cost of energy carriers;
- the demand for organic fertilizers, depending on the development of conventional and organic farming, the degree of soil depletion, the possibility of soil restoration by traditional methods, for example, by using animal waste.

The design of a recycling system in sustainable logistics systems is based on the rationale for the next steps in the design analysis.

Stage 1. Design and technical part. The implementation of the design part and the assessment of investments in the equipment "Earth Revival", production facilities and communications also presuppose binding to specific conditions. Within the framework of the project "Innovative technology for fast recycling of sewage sludge into organic fertilizers" No. 1.2.1.1/18/A/001, Earth Revival conducted research on the experimental development and industrial implementation of an accelerated method for the production of high-quality organic fertilizers from municipal sewage sludge. In the course of laboratory experiments and bench tests, the conditions for thermal disinfection of sediments were determined - the thickness of the sediment layer, the air temperature in the disinfection oven and the processing time of the sediment, as well as the conditions for accelerated maturation of the fertilizer - the choice of a bioactivator, its consumption, the processing time of the pasteurized material with a biologically active additive, the intensity mixing pasteurized material with a biologically active additive (Dubova L., Cielava N., Vibornijs V., Rimkus A., Alsina I., Muter O., Strunnikova N., Kassien O.; 2020).

At the industrial plant, the temperature and speed modes of operation of the conveyor-type disinfection oven, as well as the modes of operation of the maturing unit with periodic stirring, have been worked out. The layout of the "Earth Revival" unit and the location of the main units of equipment for MSS processing are shown in Fig. 1.

As a result of preliminary modelling, a pilot industrial plant for obtaining fertilizers from domestic wastewater sludge was designed, built and put into operation, including the following main components and assemblies:

1. Raw material loading system.
2. Pasteurization unit, which consists of the following elements (Fig. 2):

- thermo constant container with an autonomous climate system;
- pasteurization chamber with vibration transport system and heaters located along the vibration transport system, made in the form of a conveyor;
- heating elements in the form of fast-mounted infrared heating panels;

- material feeding device located at the beginning of the conveyor;
- pasteurization chamber, consisting of a heating cabinet, inside of which the sediment is moved and heated.

3. Pipeline system for transferring pasteurized semi-finished products.
4. maturation unit, including the following technical elements (Fig. 3):

- thermo constant container;
- technological bath;
- platform with mixers;
- loading and unloading control sensors;
- connected elements of the unloading device.

5. Fertilizer unloading system.
6. Systems of recuperation, ventilation, sorbent supply, mobile systems for activator, sorbent supply, emergency cleaning, etc.
7. Automated control system for material and information logistics flow.The scientific and technical value and novelty of the completed project are as follows:

- on an industrial scale, the parameters of the plant for the accelerated production of fertilizer from sewage sludge were determined (temperature conditions, consumption and reproduction of a biologically active additive, optimal values of moisture content of raw materials, intermediate products and products, criteria for adding various sorbents;
- a protocol of actions has been defined that ensures complete disinfection of raw materials;
- for the first time during the passage of the pasteurized material in the disinfection chamber, a vibration effect was used;
- selected the speed of movement of the material in the pasteurization chamber;
- the optimal thickness of the material layer for the given kinematic and temperature parameters has been established, which ensures reliable disinfection of raw materials;
- the optimal ratio of the power of ventilation, recuperation systems and heating has been established, taking into account the distance to the surface of the pasteurized material and the speed of its movement along the conveyor;
- the operation of the pasteurization chamber was tested with raw materials of different consistency (with a moisture range of ~ 70-85%), it was found that the pasteurization chamber can process 25-35 m3 (depending on the initial moisture content) of raw materials per day in a continuous mode;

- operation of the maturation tank is tested at full load (~ 30 m3) in continuous mode with material of different consistency (with a humidity range of ~ 17-77%);
- the boundary parameters of material moisture were tested for the corresponding nodes of the transport system at the stages of raw material supply, transfer of pasteurized material, unloading of the finished product and packing of fertilizer;
- the boundary and optimal parameters of the maturation chamber loading have been determined;
- the relationship between the parameters of the material loaded into the maturation chamber and the maturation period of the fertilizer has been determined;
- by flexible regulation of the intensity of moisture extraction - depending on the moisture level of the mixture of pasteurized material and activator - a stable maturation period of 5 days has been achieved from the moment of formation of the above mixture. This is from This text must be specified, because this is an article, and not an advertisement or the conclusion of a report or project, to give at least some numerical data on the parameters in the form of a table or figure.

**Stage 2. Economic feasibility study of the project**

The cost of the project unit "Earth Revival" is designed for the production of 15–17 tons of fertilizers (in terms of mass humidity ~ 50%) per day when it is designed on the territory of Ukraine.

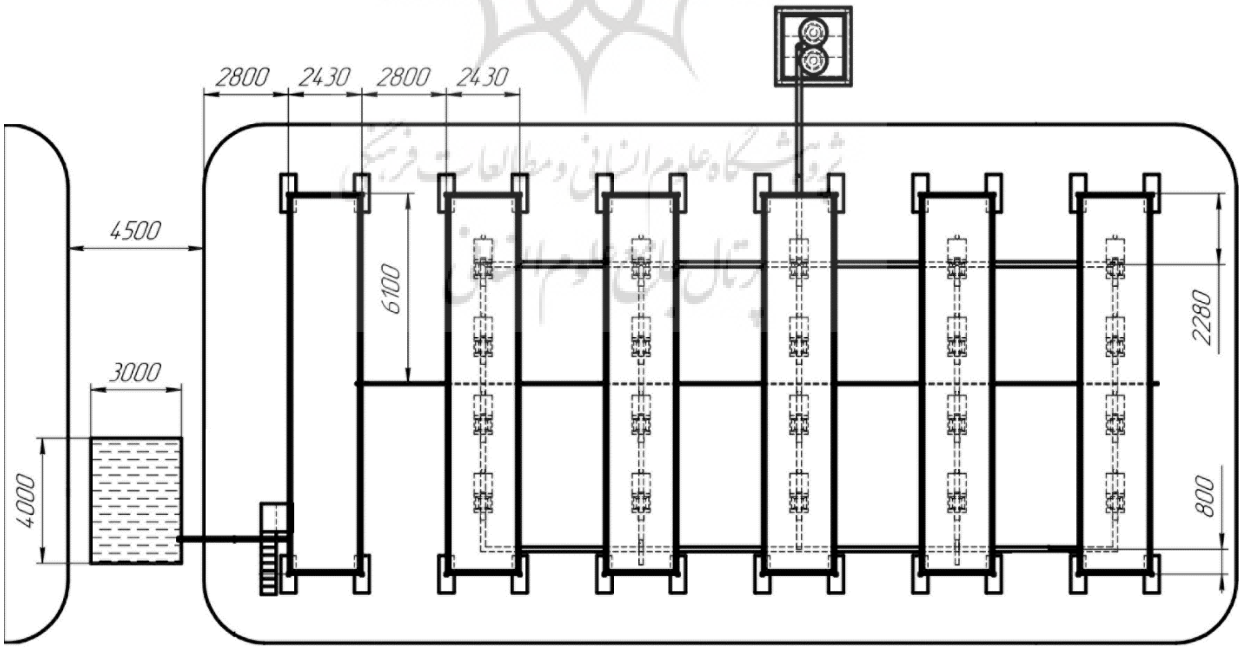


Fig. 1. Top view of the "Earth Revival" installation, from left to right: raw material hopper and raw material loading unit, pasteurization chamber; a row of five maturation tanks and, above, a unit for unloading the finished product

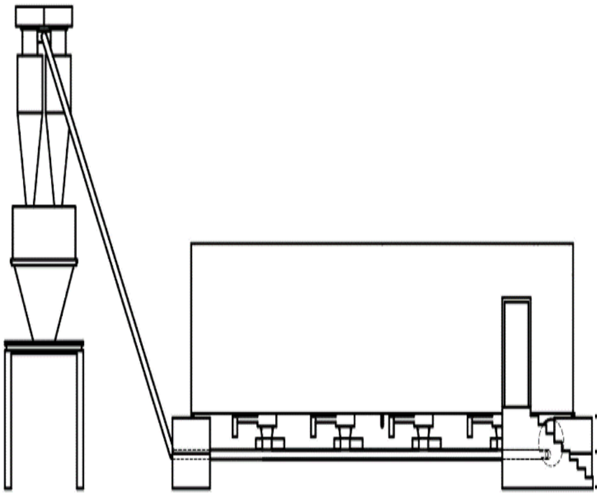

Fig. 2. View of the installation from the side of the pasteurization unit

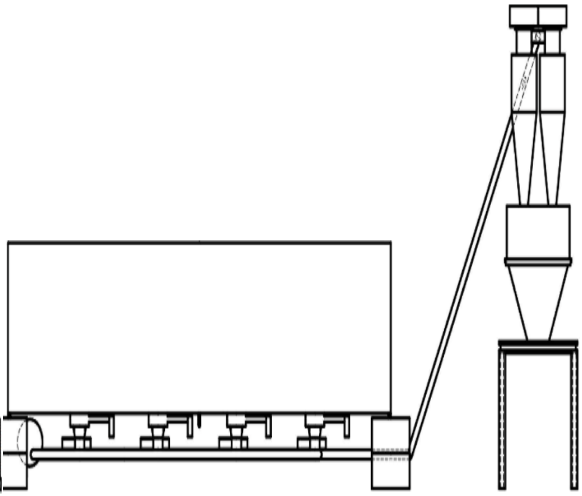

Fig. 3. View of the plant from the side of the maturation unit

The adaptation of production to existing premises and communications, as a rule, should not be a problem. At the same time, premises and communications must meet the following basic criteria:

- production workshop (heated in winter, premises from 150 sq. m) And control room (5-6 sq. M., Next to the workshop);
- warehouses (dry, unheated premises, the area depends on the volume of production and the speed of implementation - filling the volume of a 40-foot container takes about 2 days with the operation of one unit that processes 25-35 tons of WWS per day);
- administrative and sanitary, for personal and work clothes, personal hygiene;
- connection to the power grid (to ensure the operation of mechanisms, ventilation, electronics and household lighting) and / or gas mains;
- transport communications (permissible vehicle weight not less than 18 tons);
- water supply and sewerage;
- distance to the source of raw materials;
- the possibility of direct supply of MSS to the object;
- the possibility of installing a sanitary zone corresponding to the third hazard class.

One installation is designed for the production of 15-17 tons of fertilizers per day, with three-shift work. Thus, it is possible to produce up to 5500 tons of fertilizers per year. With a production cost of $30 per ton of fertilizers and the world price of the closest analogs of more than $130 per ton, the proceeds will amount to more than $500 thousand per year. Thus, the recoupment of costs for the introduction of technology, equipment and other costs can reasonably be determined in 2-3 years.

The method is based on a number of technological and logistic solutions that allow replacing the process of the traditional method of obtaining organic fertilizers using composting, eliminating harm to human health and the environment, while maintaining all the positive aspects of the natural process.

In addition, the method is economically justified, since instead of expensive or dangerous methods of handling MSS, it provides for the use of fertilizer obtained as a result of its processing.

Based on the population size, we will calculate the loss of organic matter with an irrational approach to waste disposal and the potential volume of organic fertilizer production. Unlike all existing waste treatment methods, which are costly, the developed project is profitable. Considering that the cost per ton of MSS for disposal, discharge into the sea or incineration is about $30, $40 and $90, respectively, we will calculate the main economic indicators of our project.

**To calculate the mass of fertilizers produced, it is necessary to calculate the mass of the sludge formed at the treatment plant**

So, in the data for large cities (for example, Istanbul, Paris, Moscow) it is indicated (Khramenkov S. V., Pakhomov A. N., Ganin A. V.; 2003) that the population of ~ 15-18 million accounts for about 11 million cubic meters / year of human waste, which corresponds to 0.9 million cubic meters / year of dewatered WWS per year. Thus, about 2.5 thousand tons of dehydrated WWS or about 0.15 kg of dehydrated substance per person are formed per day. Thus, the basis of the cost of manufacturing the finished product is formed by the costs required for the dehydration process. This, in turn, depends on the moisture content of the incoming raw materials and the choice of heat carrier. This dependence, as well as other factors, must be considered in more detail in relation to each object separately. The calculation of the main factors affecting the cost for the implementation of the project in Ukraine is given below (Table 2).

Thus, the basis of the cost of producing organic fertilizers based on MSS processing is formed by energy costs associated with the technological process, the basis of which is water evaporation. Cost of energy consumption of MSS processing into organic fertilizers is given in Table 3.

Table 2. Calculation of key indicators forming the basis of production costs of organic fertilizers at the Earth Revival plant in Ukraine

| ENERGY CONSUMPTION FOR EVAPORATION OF WATER FROM 1 Ton MSS WITH INITIAL HUMIDITY OF 80%<br>* TOTAL VOLUMES OF VAPORIZED WATER ARE INDICATED AT EACH SUBSEQUENT STAGE - TAKING INTO ACCOUNT WATER VAPORIZED AT PREVIOUS STAGES | | | |
|---|---|---|---|
| MSS (1 ton.; 80% HUMIDITY) | Weight of water part, kg. | MJ | kW |
| If humidity decreases from 80% to 75% it is required to evaporate 200 kg. water.<br>This step can be cheapened by preliminary mechanical removal of water using coagulants | 200 | 460 | 127,88 |
| With a subsequent decrease in humidity from 75% to 70% another 133 kg. required to be evaporated.<br>70% humidity is the level at which the organic mass can be considered fertilizer.<br>Under our conditions, this process should be started in the furnace, continued in the storage chamber, and completed in the maturation chamber. | $\frac{200+133}{333}$ | $\frac{460+305{,}9}{765{,}9}$ | $\frac{127{,}88+85{,}4}{212{,}92}$ |
| With further reduction of humidity from 70% to 60% of humidity another 157 kg. required to be evaporated.<br>This can be done already at the maturation stage, which does not require the capacity of the pasteurization furnace. | $\frac{333+157}{500}$ | $\frac{765{,}9+384{,}1}{1150}$ | $\frac{212{,}92+106{,}78}{319{,}70}$ |
| At the next step of reducing humidity from 60% to 50% another 100 kg. required to be evaporated. | $\frac{500+100}{600}$ | $\frac{1150+230}{1380}$ | $\frac{319{,}70+63{,}94}{383{,}64}$ |
| OTHER ENERGY COSTS ITEMS (EXCLUDING MECHANISMS) | | | |
| Heating of 1 ton of MSS by 55 °C (for example, from 15 to 70 °C) at humidity of 80%.<br>This heating is necessary regardless of humidity | – | 14 | 39,48 |
| Due to a significant number of variables (material texture, features of bio-chemical flow, including exothermic processes, and their use, external environmental factors during ventilation and recovery, etc.), the calculation of energy costs is given approximately to determine the energy class of the equipment. Practice has shown that real indicators for Odessa conditions are no more than 300 kW in the coldest period. | | | |

Table 3. Data required when calculating the cost of energy costs

| **Specific heat of water evaporation (1 kg./MJ) at 70 °C, normal pressure** | **2.3** | **MJ** |
|---|---|---|
| 1 MJ/ kW | 0.278 | kW |
| Calorific value of natural gas (36 MJ/m$^3$ for example) | 36 | MJ/m$^3$ |
| kW/USD (on the example of Ukraine). | 0,1 | USD |
| Gas infrared heater, 80% efficiency | 0.8 | |
| Electric heater, efficiency 90% | 0.9 | |
| Heat loss, conditionally 20% | 0.8 | |
| Power consumption (in 1 hour) of various driving and mixing units and mechanisms | 60 | kW |
| Amount of MSS (80% humidity). | 1 | ton |
| Amount of fertilizer (in terms of 50% wet). | 0.6 | ton |

According to preliminary calculations made on the basis of data obtained for the Odesa region, energy expenditures will amount to about $15 per ton of MSS with an initial humidity of 80%. Thus, the cost of energy spent on the production of 1 t of fertilizer with a humidity of 50% will be about $22.

The cost of the final product, taking into account salaries, social payments and internal logistics, doubles, which will amount to approximately $40 per ton of fertilizers for the Odesa region

Table 4. Calculation of key indicators forming the basis of production costs of organic fertilizers at the Earth Revival plant in Kuwait

| **Estimated: for Kuwait** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Energy costs for processing 1 t. sewage sludge** | | | | **Or gas** | **Or electricity** | | |
| Raw material, "fresh" | Sewage sludge (1t.; 80% humidity) | Dry material/ water, kg | Vaporisation, kg | MJ | Gas, m3 | kW | El, KD. | El, USD |
| | Warming up of 1 t. sludge from 25 to 80°C (80% humidity) | 200 / 800 | - | 142 | 3,94 | 39,48 | 0,08 | 0,26 |
| | Humidity 80% | 200 / 800 | 0 | 0 | - | - | - | - |
| | Thermal dehydration to 75% | 200 / 600 | 200 | 460 | 12,78 | 127,88 | 0,26 | 0,85 |
| Raw material after pasteurisation. | Thermal dehydration to 70% (max humidity level for organic fertilisers) | 200 / 467 | 333 | 765,9 | 21,28 | 212,92 | 0,43 | 1,42 |
| | Termal dehydratation to 60% | 200 / 300 | 500 | 1150 | 31,94 | 319,7 | 0,64 | 2,13 |
| | Termal dehydratation to 50% (optimal humydity level for organic fertilisers) | 200 / 200 | 600 | 1380 | 38,33 | 383,64 | 0,77 | 2,56 |
| | Energy for technical operations (electricity) | - | - | - | - | 60,00 | 0,12 | 0,40 |
| Cost price per 1t of raw material* | Pasterised material (70% humidity). | | | | | | 0,62 | 2,08 |
| | Pasterised material (50% humidity). | | | | | | 0,97 | 3,22 |
| | Efficiency of heat-power aggregates (80% gas; electric 90%). | | | | | | 0,92 | 3,06 |
| Total energy cost price ** | Efficiency (after extra heat loss; conditionally taken as 20%). | | | | | | 1,12 | 3,73 |

Full and accurate costing, including taxation, is possible only with reference to the specific conditions of the city, taking into account the peculiarities of the urban infrastructure and the influence of factors such as taxes, benefits, savings of allocated funds, etc.

For example, the calculation of a similar project for start-up and implementation in Kuwait indicates a difference in the cost of MSS processing and organic fertilizer production at the Earth Revival plant, depending on the business conditions in each country (Table 4). As a result of the difference in the cost of energy carriers, the final cost of the product changes.

Based on the presented calculation of the cost of organic fertilizers obtained by processing MSS, we will consider 2 methodological approaches to calculating the production of finished fertilizers for the conditions of large cities.

Based on the fact that an adult on average produces ~0.4 – 0,5 kg of wet (90%) excrement per day and ~15 kg of dry organics per adult per year 15 kg of dry organics per year are 0.041 dry. kg/day, that at humidity of 90% and with increase of natural (less than 10%) fraction of inorganic compounds makes the same 0.4-0.45 kg of excrement per adult person per day (Daisy A., Kamaraj S.; 2011).

Thus, data from both sources and both calculation systems give results of the same order. Discrepancies between the actual data of a real city and theoretical calculations based on an average adult are explained, first of all, by the mixed age composition of the population, as well as possible losses of raw materials.

Calculation of the mass of fertilizers produced per day.

For approximate calculations of the amount of MSS per day, as well as the potential amount of organic fertilizers produced per day (50% organic, 50% humidity), the following methods are proposed:

**Option 1**

As noted above, an adult produces 0.4 kg of wet (90%) excrement per day. According to the same source, the child produces 0.2 kg, and the teenager 0.3 kg. On average, we will accept 0.3 in the population.

For calculation it is proposed to use the following procedure (1), (2):

$$M_{(t.sl/day)} = N_{pop} \times 0{,}3_{kg} / 1000_{kg} \tag{1}$$

$$M_{(t.fert/day)} = M_{(t.sl/day)} \times 0{,}6_{(recyclingkoefficient)} \tag{2}$$

where $M_{(t.sl/day)}$ is the mass of WWS per day;

$M_{(t.fert/day)}$ is mass of fertilizers produced;

$N_{(pop)}$ is number of population;

$0{,}3$ is mass of fecal discharges averaged by humidity and age per person/day;

$0{,}6_{(recyclingkoefficient)}$ is the ratio of 0.6 fertilizer to MSS was obtained by us experimentally at a pilot plant in Odesa.

For example, for a city with a population of 1 million people.

$$M_{(t.sl/day)} = 1000000 \times 0{,}3_{kg} / 1000_{kg} = 300_{m},$$

$$M_{(t.fert/day)} = 300_{m} \times 0{,}6_{(recyclingkoefficient)} = 180_{m}.$$

**Option 2**

The calculation option, based on the amount of organics per person per year and the amount of organics (50%) in fertilizers with a humidity of 50%, is carried out according to the formula (3):

where $M_{(t.fert/day)}$ - mass of fertilizers produced;

$N_{(pop)}$ is number of population;

$15_{кг}$ is amount of organics per adult per year;

$2$ is coefficient at ash content 50%;

$2$ is coefficient at humidity 50%.

For example, for a city with a population of 1 million people.

$M_{(t.fert/day)} = 15_{(kg.org/year)} / 365_{days} \times 2{,}0 \times 2{,}0 \times 1000000 = 164383_{кг}$ or 165 t

**Option 3**

According to Swedish data for 1 million people. (all ages together) account for about 56 tons of dry MSS per day, which at a humidity of 80% gives 280 tons of raw materials/day using formulae (4) and (5):

$$M_{(t.sl/day)} = M_{(t.dry.sl/day)} \times 5_{humidity80} \quad (4)$$

$$M_{(t.fert/day)} = M_{(t.sl/day)} \times 0{,}6_{(recyclingkoefficient)} \quad (5)$$

where $M_{(t.sl/day)}$ is MSS weight per day;

$M_{(t.dry.sl/day)}$ is Mass of dry MSS per million of Sweden's urban population;

$M_{(t.fert/day)}$ is mass of fertilizers produced;

$5$ is coefficient at humidity 80%;

$0{,}6_{(recyclingkoefficient)}$ is the ratio of 0.6 fertilizer to MSS was obtained by us experimentally at a pilot plant in Odessa.

For a city with a population of 1 million people.

$$M_{(t.sl/day)} = 56_{(m)} \times 5 = 280_{m},$$

$$M_{(t.fert/day)} = 280_{m} \times 0{,}6 = 168_{m},$$

Thus, the first, second and third methods of counting give from 160 to 180 tons/d of organic fertilizers (in conditional terms for mass humidity of 50%) per day per million adult population, a tonnage of dry MSS of about 60 tons/d, and a wet (80%) of about 300 tons/d or slightly less, if not artificially differentiated by age.

3 Stage. Environmental component of the project. The proposed project of an environmentally sustainable logistics system is cyclical and focused, especially on solving the environmental problems of cities and regions. That is why the environmental part of the project provides for the introduction of an effective wastewater treatment system in the ecological system of cities and regions. The problem of recycling domestic sewage sludge is the main problem of logistics systems and infrastructure of large cities. The accumulation of large amounts of this type of precipitation leads to pollution of soils, surface and groundwater. Since municipal wastewater sludge is a mass with a high content of biogenic components, its main use is as fertilizer.

The Earth Revival project, which involves the processing of domestic wastewater sludge into organic fertilizer, has shown its effectiveness in conducting comprehensive biological studies of its impact on the soil. The effectiveness of the obtained fertilizer was tested on individual plants and it was shown that this fertilizer increases yield. To increase the biological value of the obtained fertilizers, effective microorganisms were isolated.

There is evidence in the literature about the study of effective microorganisms involved in the metabolism of nitrogen compounds from organic fertilizers, however, for active sludge preparations, similar studies were conducted for the first time. For the first time, an attempt was made to create a consortium of these microorganisms and an assessment of their effectiveness was made.

Based on the studies conducted, it is possible to choose effective methods of treating MSS and active sludge, which allow to obtain high-quality organic fertilizer in a short time, which characterizes the practical significance of the study in terms of its impact on the ecosystem.

A detailed study of microbiological fertilization on plants showed the following practical results:

1. Plants grow best in combination with a wastewater sludge preparation and mineral fertilizers.

2. Cucumbers are the most sensitive to the preparation of sewage sludge.

3. The addition of bacteria in most cases improves the physiological state of plants compared to the non-bacterial version. In most cases, consortium results are better than that of free-living nitrogen fixers (Azotobacter sp).

All studies were conducted in accordance with the methods set out in the official records of the working group.

The effect of microbiological fertilizer on plants was evaluated by growing leaf mustard, cucumbers and corn. The evaluation was carried out by measuring the weight of plants, the number of leaves, the thickness of the trunk and the amount of chlorophyll in the green mass of plants. Plant cultivation was carried out on various peat-based substrates with the addition of bio-humus, test organic fertilizer and mineral fertilizer additives to correct NPK, nitrogen fixers and a selected consortium of microorganisms.

The proposed technology for accelerated processing of MSS by Earth Revival into organic fertilizers is designed to receive standard dehydrated sludge. The use of the obtained organic fertilizer is possible both for increasing yields and for restoring soil fertility, as well as a base product for more complex organic and organo-mineral fertilizers. The sale can be made in bulk for agricultural enterprises, as well as in small packaging for the private sector.

The content of various trace elements in the organic fertilizer produced by Earth Revival, depending on the region of origin of the raw materials and the characteristics of their production in each country, is presented in Table 5.

Table 5. Table of comparison of organic fertilizers [compiled by authors on the basis of research results (Dubova L, Cielava N, Vibornijs V, Rimkus A, Alsina I, Muter O, Strunnikova N and Kassien O.; 2020)

| **Mass fraction mg/kg of dry matter** | | **Cd** | **Co** | **Cr** | **Cu** | **Mn** | **Ni** | **Pb** | **Zn** | **Hg** | **Sr** | **Mo** | **Se** | **As** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ER Odessa, Ukraine (max. range of all results) | | 0,15 | | | 81 | 188 | 25 | 149 | 409 | ~0 | | - | | |
| Dobele, Latvia (studge) | | 3 | | 315 | 181 | | 41 | 49 | 94 | 0,12 | | | | |
| Jelgava, Lativa (sludge) | | <0,17 | | 82,8 | 102 | | 44 | 29,2 | 492 | 1,39 | | | | |
| Ukraine | 1gr | 3-5 | 5-20 | 100-400 | 100-300 | 250-750 | 50-75 | 100-200 | 300-1000 | 2-5 | 50-70 | - | - | - |
| | 2gr | 5-15 | 20-50 | 400-600 | 300-700 | 750-1500 | 75-150 | 400-600 | 1000-2000 | 5-10 | 75-100 | - | - | - |
| | 3gr | 16-30 | 50-100 | 600-750 | 700-1500 | 1500-2000 | 150-200 | 600-750 | 2000-2500 | 10-15 | 100-300 | - | - | - |
| | 4gr | 30-40 | 100-150 | 750-2000 | 1500-2500 | 2000-3000 | 200-400 | 750-1200 | 2500-4000 | 15-20 | 300-500 | - | - | - |
| | 5gr | 30-40 | 150-200 | 2000-4000 | 2500-4000 | 2500-4000 | 400-600 | 1200-1500 | 4000-7000 | 20-30 | 400-500 | - | - | - |
| **EC** Directive №86/278 | | 20-40 | - | - | 1000-1750 | - | 300-400 | 750-1200 | 250-4000 | 16-25 | - | - | - | - |
| Netherlands* | | 1 | - | 75 | 75 | - | 30 | 100 | 300 | 1 | - | - | - | - |
| Sweden* | | 2 | - | 100 | 600 | - | 50 | 100 | 800 | 3 | - | - | - | - |
| Germany* | | 10 | - | 900 | 800 | - | 200 | 900 | 2500 | 8 | - | - | - | - |
| France* | | 15 | - | 1000 | 1000 | - | 300 | 900 | 3000 | 10 | - | - | - | - |
| Poland | I & II | 10 | - | 500 | 800 | - | 100 | 500 | 2500 | 5 | - | - | - | - |
| | III | 25 | - | 1000 | 1200 | - | 200 | 1000 | 3500 | 10 | - | - | - | - |
| | IV | 50 | - | 2500 | 2000 | - | 500 | 1500 | 5000 | 25 | - | - | - | - |
| USA* | | 50 | - | 500 | 750 | - | 150 | 500 | 1500 | - | - | - | - | |
| USA Class A&B | | 85 | | 3000 | 4300 | | 420 | 840 | 7500 | 57 | | 75 | 100 | 75 |
| USA EQ** | | 39 | | 1200 | 1500 | | 420 | 300 | 2800 | 17 | | - | 36 | 41 |
| Russian Federation (optional recommendation) | I | 2 | - | 90 | 132 | - | 80 | 130 | 220 | 2,1 | - | - | - | 2 |
| | II | 15 | - | 500 | 750 | - | 220 | 250 | 1750 | 7,5 | - | - | - | 10 |
| Oman | | 20 | - | 1000 | 1000 | - | 300 | 1000 | 3000 | 10 | - | 20 | 50 | - |
| Mass fraction mg/kg of dry matter | | Cd | Co | Cr | Cu | Mn | Ni | Pb | Zn | Hg | Sr | Mo | Se | As |

## Conclusion

The presented recycling project in sustainable logistics systems in the field of wastewater treatment solves the problem of creating sustainable logistics systems based on recycling **in the focus of information technology management**. The traditional view of recycling is based mainly on the problem of recycling secondary waste and the creation of logistics channels that form the material flow for the purpose of recycling waste without an information technology management system. However, this area does not consider wastewater treatment methods, referring these technologies to the field of utilities. The solutions proposed in this work in the field of implementation of the waste water treatment project, by creating closed-loop logistics systems, allows solving a number of problematic issues not only in the field of urban communications and infrastructure, but also in terms of managing and coordinating material and information logistics flows. The project is integrated and aims to create urban systems within the framework of the Green City concept, as it allows the implementation of all directions of the sustainable development strategy based on the use of information management technologies. The design technology allows you to completely close the logistics cycle of the supply and processing of MSS into finished products in the form of organic fertilizers using an information technology management system in logistics. The second stage of this project will be related to the formation and strategy of supply chain management of organic fertilizers obtained the information component of which will be integrated into a single system.

## Conflict of interest

The authors declare that no competing financial interests or personal relationships that could influence this paper exist.

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