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INVESTIGATION OF POSSIBILITIES FOR UPCYCLING INSTEAD OF DISPOSAL SEWAGE SLUDGE

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INTRODUCTION

Wastewater treatment using biological sludge/microorganisms is one of the oldest methods of wastewater treatment, but it is still used today because of its effectiveness. Waste sewage sludge is an inevitable by-product of aerobic wastewater treatment, and it consists from a set of microorganisms, mostly bacteria, which through their metabolism reduce the organic load of which waste water is composed; products of the metabolism of microorganisms as well as non-degraded organic and inorganic substances found in waste water [1,2].
In the usual process of purifying waste water by aerobic processes, biological, also known as „activated“, sludge is separated from the process and goes to further treatment of thickening and stabilization. Sludge stabilization can be aerobic or anaerobic depending on the way of the sludge treatment. Some of the ways of using sludge are: biogas production, incineration, composting, use in agriculture, etc [3,4].

Sludge from wastewater treatment

Regardless of whether it was stabilized, thickened, conditioned or anaerobically treated sludge, significant amounts of sludge still remain after the recent treatments, which represent a relatively large environmental problem. Furthermore, sludge is mostly inadequately disposed of and represents a danger to the living world and human health in the end [5].
On the other hand, the application of waste sludge for other purposes, primarily in agriculture, is still in the experimental phase due to the potential dangers that sludge can bring if it is applied. According to the rulebook in force in the FBiH [7], it is not at all possible to use sludge in agriculture for food production, while the previous act [8] allowed its use if the sludge meets certain threshold values. In addition to the above, in the countries of the European Union, the use of processed treated sludge in agriculture is also allowed if certain limit values are met. On the example of the neighboring Republic of Croatia [9], when sludge is used in agriculture, in agriculture it is allowed to use only treated sludge that

- contains heavy metals in quantities that do not exceed the permitted values prescribed by Article 5 of the Ordinance [9]
- contains organic substances in quantities that do not exceed the permitted values prescribed by Article 6 of the same Ordinance,
- is stabilized in such a way that pathogenic organisms, potential causes of disease, are destroyed in it.

In accordance with the above mentioned, the experimental part of this research was also carried out with the aim of stabilizing the waste sludge in order to change its characteristics so that it does not pose a danger to the environment, while revealing the possibility of its subsequent application.

METHODOLOGY

Materials

Waste sludge from the municipal waste water treatment plant of the city of Živinice was used as the base material for this research.
Raw pyrophyllite shale from the Parsovići deposit near the city of Konjic B&H provided by AD Harbi doo Sarajevo.

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Microorganisms based eMB starter (lactic acid bacteria, photosynthetic bacteria and PDM 7 group of microorganisms) is produced by EM plus.
Earthworms (*Eisenia fetida*).

Methods

In order to confirm the success of individual procedures, a series of analytical tests of physico-chemical and biological parameters of sludge were performed, realized using standard and modified standard methods according to BAS EN ISO, EN ISO and APHA methodology.
The characterization of raw material, waste sludge, and forming mixtures after treatments by measuring the pH value and determining total dry matter (TS), volatile organic matter (VS), total Kjeldahl nitrogen (TKN) and total phosphorus (TP). The methods used in the analysis of physico-chemical characteristics are standard methods and modified standard methods for wastewater testing [10]
The pH value was measured by a digital measuring device with direct immersion of the electrodes in samples, using pH meter Mettler Toledo FE20/EL20. Prior to each measurement, the control of the measuring device was performed using standard buffer pH 4.01, 7.01, 10.01.
Determination of dry and volatile organic matter was carried out according to the standard Method [10].
For the determination of the content of total Kjeldahl nitrogen, Method 4500 [10] was used. The method consists of three parts: digestion at a temperature of 340°C in the presence of concentrated sulfuric acid and Kjeldahl catalyst, distillation in the presence of NaOH where the distillate is absorbed into a 2% boric acid solution and titration with 0.1 M HCl in the presence of indicator bromocresol green.
Total phosphorus content has been determined by the standard method BAS EN ISO 6878:2006.
Heavy metals were determined according to EN 16174:2012 [11] by atomic absorption spectrometry.
US EPA SW-846 Test Method 3546 [12] was used to determine PCBs.

Design and execution of experiment

The following experiments were carried out with the aim of final processing of the sludge:
1. microbiological sludge treatment;
2. stabilization of sludge with natural materials;
3. biological sludge treatment.

Microbiological treatment of sludge was carried out using microorganisms eMB starter lactic acid bacteria, photosynthetic bacteria and PDM 7 group of microorganisms produced by EM plus.
In this part of the experiment, 1 m^3 of sludge was used after dehydration on a mechanical press (sludge with approx. 18% TS) and was mixed with microorganisms in a liquid state in such a way that a portion of mixed microorganisms was added to the cleaned, concrete substrate using a sprayer, and then sludge was applied in a layer of 10 cm. 5 L of microorganisms were used per 1 m^3 of sludge. After 7 days, the pile was mixed for the first time and left to rest again. Mixing was done every 7 to 10 days. After 45 days, a sample was taken and subjected to analysis.

Fig. 1: Microbiological treatment of sludge

Stabilization of sludge with natural materials was carried out by mixing it with pyrophyllite shale from the Parsovići Konjic bed in BiH provided by AD Harbi. The sample was taken for analysis after 102 days.
1 kg of pyrophyllite shale was added to 10 kg of dehydrated sludge, mixed and left to stand. The sample was mixed every 7 days.

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Fig 2: Stabilization of sludge with natural materials

Biological treatment of sludge was carried out using California earthworms (*Eisenia fetida*).

In this part of the experiment, 1 m^3 of dehydrated sludge was mixed with 50 kg of earthworm compost. The sample was mixed every 2 to 3 days to achieve as homogeneous a mixture as possible for the earthworms to process. The remains of fruit and paper were removed from the compost, and the earthworms had at their disposal just a sludge and smaller remains of compost that could not be removed.

Fig 3: Biological treatment of sludge

RESULTS AND DISCUSSION

Based on tests of treatment of sewage sludge by different methods the results are shown in Table 1. For the sake of simpler presentation of the results, individual samples of the experimental research are marked as follows:

0- raw waste sludge from the municipal wastewater treatment plant in Živinice
1- microbiologically treated sludge after 45 days
2- physically stabilized sludge using natural material after 30 days

Table 1: Results different treatment sewage sludge

parameter/sample	unit	0	1	2
pH	-	8,08	7,45	7,10
TS	%	17,75	22,19	48,32
VS	%	9,82	12,56	12,89
TP	g/kg	186,78	156,48	41,62
TKN	g/kg	9,67	11,07	11,70

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Fe	mg/kg	0,2024	0,217	0,00
Mn	mg/kg	0,068	0,08	0,00
Cu	mg/kgTS	118,00	77,70	37,80
Cr	mg/kgTS	41,70	56,10	1,14
Pb	mg/kgTS	27,90	52,70	18,80
Ni	mg/kgTS	123,00	146,00	79,80
PCB	mg/kgTS	0,01	0,01	0,01
streptococci of fecal origin		+	+	-
coliform bacteria of faecal origin - Eikman test		+	+	-
proteus species		+	+	-
pseudomonas aeruginosa		+	+	-
sulfido-reducing clostridia in 10 ml		+	+	-

Based on the results shown in Table 1, especially from the physical-chemical-biological characteristics of raw and differently treated sludge, it is clearly visible that the basic characteristics did not change after processing. The exception, quite logically, is sample number 2, because a material with a completely different composition compared to the sludge was added to the raw waste sludge, i.e. Prilophyllite shale, which belongs to clays (alumino-silicate), is of inorganic origin, while on the other hand, waste sludge is mostly of organic origin. The addition of pyrophyllite shale resulted in a significant increase in the proportion of dry matter (TS) and changed the ratio of organic matter (VS), total nitrogen (TKN) and total phosphorus (TP) in the raw waste sludge. The content of metal elements is lower in treated compared to untreated sludge, which directly improves the possibility of applying the material. In addition, it should be pointed out that the content of metal elements are significantly below the permissible limit prescribed by the Rulebook on determining the permitted amounts of harmful and dangerous substances in the soil and their testing methods [8] and the Rulebook on the management of sludge from devices for wastewater treatment when sludge is used in agriculture [9].
The presence of harmful bacteria, which represent the basic limitation when it comes to the application of waste sludge, after treating the sludge with pyrophyllite shale from the deposit "Parsovići" Konjic Bosnia and Herzegovina (AD Harbi) was significantly changed compared to the content of the same bacteria in the raw sludge. Namely, the use of pyrophlite shale greatly minimizes the impact of pathogenic bacteria, even more so the presence of bacteria was not recorded after this treatment of waste sludge.
During the experiment on microbiological treatment of sludge, it was noticed that the strong and unpleasant smell of the sludge was lost, to the point that it finally had the smell of wet earth. A few days after setting up the experiment, the pile began to settle and release less water. When the sample was taken for analysis, the sludge was gray-brown in color (the color of the earth) and a large number of worms (insects, larvaes) were observed. The initial color of the sludge when performing this experiment was black (Figure 4).

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Fig 4: Sample of sludge after microbiological treatment

At the end of the process of sludge stabilization with natural materials, the color of the sludge became black, mixed with the traces of pyrophyllite. The sample had almost completely lost the unpleasant odor of sludge.
The color of the mud at the beginning of the experiment was black and remained so until the end of the experiment, except that the characteristic gray color of the pyrophyllite schist was visible in places. After the end of this experiment, the unpleasant smell of sludge, characteristic of dehydrated sludge, completely disappeared.
After about 90 days, larger parts of the compost material (paper, larger pieces of fruit) were removed from the mixture of sludge and compost with earthworms, and the experiment was extended for the next 90 days. After 6 months, smaller parts of compost material were still present in the mixture, the color of the sludge became brown (probably a biologically processed part of the sludge). It is noticeable that there is no creation of new worm beds, but the worms are still present in the mixture. A large number of small animals of the wine fly type, which is characteristic of a fermented environment, was present after 6 months of the experiment. There was no longer an unpleasant smell in the sample, the smell of earth (wet earth) prevailed. In smaller parts of the mixture there was a black color of sludge (initial color of the sludge), while in some parts the appearance of layers of black-dark brown-brown color was visible (Figure 5.).

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Fig 5: Sludge after six months biological treatment

CONCLUSION

Waste sludge from municipal wastewater treatment plants represents one of the main environmental problems in Bosnia and Herzegovina, and taking into account the composition of waste sludge, it represents a significant potential for application in energy, agricultural and/or other purposes. Therefore, it is very important to find a proper solution for its final disposal or specific application while respecting the principles of the circular economy.

Considering the results of this research, it is possible to finally dispose of the waste sludge with microbiological, physical or biological treatments, due to the change in its basic characteristics. By applying a mixture of microorganisms eMB starter and PDM 7, the unpleasant smell of waste sludge was minimized, and the volume of sludge was reduced. The appearance of new life communities is clearly visible on the treated mass, which indicates a significantly reduced toxicity of the mixture, and directs future research in a clear direction.

By using a natural clay material, in addition to minimizing the unpleasant odors of the mixture formed by mixing waste sludge and pyrophyllite slate, a material with a significantly lower moisture content and completely destroyed harmful bacteria from the family of fecal bacteria is obtained. Bearing in mind the practice of using lime ($Ca(OH)2$) at plants for the purpose of destroying harmful bacteria, which has a significantly higher aggressiveness than the applied clay, but also an extremely basic reaction, it is clear that the continuation of the research will go in the direction of using pyrophyllite shale as replacement material for the purpose of stabilization of waste sludge. In this way, a material suitable for inerting and forming a cover layer at waste disposal sites is obtained, without significant environmental negative impact.

The application of biological treatment using earthworms (*Eisenia fetida*) represents a relatively long process that results in a visually changed structure in the treated sludge mass, with a reduced impact of unpleasant odors.

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