POSSIBILITY OF USING SLUDGE FROM DRINKING WATER TREATMENT PLANT AS FERTILIZER IN AGRICULTURE AFTER E-BEAM TREATMENT: EFFECTS OF AGING

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Abstract

Using accelerators in treating waste sludge from a drinking water treatment plant is a well-known technique. Ionizing radiation is an effective method for neutralizing microorganisms from waste sludge. Sludge treated in this way can be used as fertilizer in agriculture. Treated sludge can increase the humus content of the soil, the physical condition of soils, can enrich the soil with micronutrients such as phosphorus, potassium, sulfur, calcium, magnesium, and micronutrients. However, if it is not used as a fertilizer immediately, but after a storage period, the content of microorganisms and mold in the sludge can increase, sludge can change its physicochemical characteristics, or the ratio of total nutrients. The research aimed to determine whether sludge treated with gamma radiation can be used as fertilizer, after a storage period of 15 months.

1. INTRODUCTION

Drinking water is water that is used in drink or food preparation; and potable water is water that is safe to be used as drinking water. The amount of drinking water required to maintain good health varies, and depends on physical activity level, age, health-related issues, and environmental conditions. With the increase in the world population and the decrease of natural drinking water stocks, there is a growing demand for drinking water treatment plants worldwide. Using accelerators is an effective method for neutralizing microorganisms from waste sludge [29, 30, 31]. Sludge treated in this way can be used as fertilizer in agriculture [32, 33]. Sludge can increase the humus content of the soil [34,35], the physical condition of soils [36], can enrich the soil with micronutrients such as phosphorus, potassium, sulfur, calcium, magnesium, and micronutrients [37].

However, if it is not used immediately as a fertilizer, but after a storage period, the content of microorganisms and mold content in the sludge can increase. In the paper, the total number of microorganisms and molds in the sludge were performed. The samples were examined immediately after e-beam treatment and after 15 months of storage in a dark and dry place. It was shown that the content of microorganisms did not increase after the storage period. The study showed that the samples' aging does not affect the change in physicochemical characteristics. Finally, the results shows that the heavy metal content stays into permeative values. All these values meet the Council Directive No. 86/278/EEC requirements for the use of sludge as fertilizer in agriculture

2. MATERIALS AND METHODS

2.1. Sample collection

After the flocculation process in the drinking water plant, the waste sludge samples were collected from the bottom of a precipitator. They are packed in plastic zip bags (Figure 1) and irradiated with varying irradiation doses.

FIG. 1 Waste sludge samples irradiated with e-beam

2.2. E-beam irradiation

Electron irradiation was performed at the University Centre of Electron Accelerators in Trencín, Slovakia, using a pulsed scanning beam (3.5 μs pulse duration with 120 Hz beam repetition rate) of 5 MeV electrons vertically emitted from linear accelerator UELR 5-1S. Samples were irradiated with different irradiation doses: 1 kGy, 3 kGy, 5 kGy, 10 kGy, 25 kGy. The average dose rate was 135 kG·h-1. The B3 radiochromic films/spectrophotometer dosimetric system [41] was used to control absorbed irradiation doses.

2.3. Aging

After irradiation, physicochemical characteristics, microbiological analysis, determination of heavy metals and total nutrient in sludge were performed. The same batch of sludge was stored in a dark place at 15°C for aging before subsequent analysis. The storage time length was 15 months.

2.4. Microbiological analysis

The total number of microorganisms and molds in non-irradiated samples and samples irradiated with different gamma and electronic radiation doses was determined in an accredited microbiological laboratory, following the Ph. Eur. 7.0 (2.6.12. – Microbiological examination of non-sterile products (total viable aerobic count), and 2.6.13. – Microbiological examination of non-sterile products (total viable aerobic count)). Samples were analyzed immediately after irradiation, as well after 15 months.

2.5. Determination of the heavy metal concentration in sludge

To determine the concentration of heavy metals (Cd, Co, Pb, Ni, Cr, and Cu) in sludge samples, they were dissolved in HF, HClO4, and HCl acids. After the dissolution, Ni, Cr, and Cu content were determined using AAS (Perkin Elmer PinAAcle 900T). For the quantitative analyses of As, Hg, and Se, the waste sludge samples were dissolved in HNO3, HClO4, H2SO4, and HCl acids. After the dissolution, the content was determined using Mercury Hydride System AAS (Perkin Elmer PinAAcle 900T).

3. RESULTS AND DISCUSSION

3.1. Physicochemical characteristics

Physicochemical characteristics of waste sludge treated with 25 kGy, immediately after treatment and after aging for 15 months are shown in Table 1.

TABLE 1. PHYSICOCHEMICAL CHARACTERISTICS OF SLUDGE SAMPLES COLLECTED FROM A DRINKING WATER TREATMENT PLANT

Parameter	Treated with e-beam, measured immediately after treatment	Treated with e-beam, measured after 15 months	Permitted values for sludge to be used as a soil improver
pH	5.98	5.32	4-7
electrical conductivity	1486	1488	<3000
cation exchange capacity	108	107	>25
volatile solids	46	29	-

From Table 1 one can see a slight decrease in the pH value after 15 months of storage, because of the CO_2 production and oxidation of ammonia [47]. In any case, the values obtained are still above the minimum allowable value given in the Law on Plant Nutrients and Land Breeders. The conductivity and Cation exchange capacity of the treated sludge hardly changes as a function of time. The values of solid solvents decrease over time due to the natural drying of the sludge.

3.2. Determination of total number of microorganisms and molds in sludge

Determination of total number of microorganisms and molds in sludge were performed immediately after e-beam irradiation and after 15 months to assess the impact of aging. The results are shown in Table 2.

TABLE 2. TOTAL NUMBER OF MICROORGANISMS AND MOLD ANALYSED IMMEDIATELY AFTER IRRADIATION, AS WELL AS AFTER 15 MONTHS OF STORAGE

Dose, kGy	0	1	3	5	10	25
Total number of microorganisms (cfu·ml^{-1}), June 2019	24500	12500	1700	80	0	0
Total number of microorganisms (cfu·ml^{-1}), September 2020	5200	1000	500	0	0	0
Molds (cfu·ml^{-1}), June 2019	95	22	18	0	0	0
Molds (cfu·ml^{-1}), September 2020	80	15	7	0	0	0

From Table 2, one can see that the total number of microorganisms decreases significantly even with small doses of radiation. These results are expected and found in the literature [29, 30, 31, 48]. A dose of 5 kGy is sufficient to reduce the total number of microorganisms to the level allowed for sludge to be used as fertilizer in agriculture. A dose of 10 kGy is adequate for the destruction of all microorganisms in the sludge.

The second row shows the total number of microorganisms of the same samples after aging for 15 months in closed bags. The total number of microorganisms decreases concerning the samples analysed immediately after irradiation. It is explained by the lack of oxygen in the bags. As a result, microorganisms cannot grow [49].

Also, aging does not affect the increase in mold content in all samples. A dose of 5 kGy is enough to neutralize all the mold from the samples.

3.3. Determination of heavy metals in sludge

According to the EU Directives, the maximum quantity of heavy metals in sludge that could be used as a fertilizer is defined [52, 53]. Table 3 shows the limit values of heavy metal concentrations in sludge for agricultural use (mg / kg dry matter) and the content of heavy metals before and after e-beam irradiation with a dose of 10 kGy. This dose was chosen because 10 kGy was sufficient to eliminate all microorganisms from the dried treated waste sludge. Values are shown for sludge tested immediately after ionizing radiation treatment and after 15 months of storage.

TABLE 3. THE CONTENT OF HEAVY METALS BEFORE AND AFTER IRRADIATION WITH A DOSE OF 10 kGy

Heavy metal	Limit values, mg/kg dry matter	Irradiated with a dose of 10 kGy e-beam irradiation, measured after treatment mg/kg dry matter	Irradiated with a dose of 10 kGy e-beam irradiation, measured after 15 mounts mg/kg dry matter
Cadmium	20 to 40	19	19
Copper	1000 to 1750	388	390
Nickel	300 to 400	54.8	55.0
Lead	750 to 1200	123	120
Zinc	2500 to 4000	170	170
Mercury	16 to 25	8.20	8.19
Chromium	100	38.5	39.1
Arsenic	29	9.70	9.70
Selenium	0.7	0.0682	0.0672

Table 3 shows that the content of heavy metals in the waste sludge obtained from the drinking water treatment plant is significantly lower than the limit values [48]. The heavy metals content was determined immediately after the treatment with ionizing radiation and after 15 months of storage. It is known from the literature that ionizing radiation can reduce some heavy metal ions, but the total heavy metal content remains the same [54, 55]. It can be concluded that this sludge is under the Directives for use in agriculture, as far as the content of heavy metals is concerned, so the irradiated waste sludge is favourable for further application as a fertilizer in agriculture.

3.4. Determination of the total nutrient in sludge

The essential nutrients (N, P, K) in the treated sludge were examined. The test was performed immediately after irradiation with a dose of 10 kGy and 15 months after irradiation. The results are shown in Table 4.

TABLE 4. THE CONTENT OF TOTAL NUTRIENT IN SLUDGE IMMEDIATELY AFTER IRRADIATION WITH A DOSE OF 10 KGY AND 15 MONTHS AFTER IRRADIATION

Nutrient	Irradiated with a dose of 10 kGy e-beam irradiation, measured after treatment %	Irradiated with a dose of 10 kGy e-beam irradiation, measured after 15 mounts %
Nitrogen	1.9	2.0
Phosphorous	1.9	1.8
Potassium	0.19	0.18

Table 4 shows that the primary nutrients' values do not change when the sludge is stored in the described manner, in closed bags in a dark and dry place. A dark and dry place protects fertilizer products from exposure to UV rays and reduces freezing risk. With UV exposure, some fertilizer granules can heat, which decomposes the nitrates contained within.

4. CONCLUSION

The use of high-energy ionizing radiation is a successful method for the deactivation of microorganisms from waste sludge. Sludge treated in this way can be used as fertilizer in agriculture. In the paper, the influence of aging on the microbiological properties of sludge treated with e-beam was investigated. It was found that after 15 months of storage, no microorganisms develop in the treated sludge if it is stored packed in plastic bags in a dark and dry place. In that case, the total number of microorganisms even decreases. The aging of sludge samples under these conditions does not affect the increase of mold content either. Also, it has been shown that aging does not affect physicochemical characteristics, changes in total nutrients, and concentration of heavy metal under these storage conditions. It can be concluded that waste sludge from drinking water treatment plants, treated with ionizing irradiation, has excellent potential to be used as fertilizer in agriculture.

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