Actual Ecologically Friendly Solving of Problem of Municipal Sludge

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Abstract* – A new eco-friendly process for rational utilization of toxic municipal sludge wastes by their transformation into fertilizer for land application has been developed. It includes promotion of alkaline vector of heterotrophic microbial metabolism in high stable biocolloidal sludge system by adding special nutrients, heavy metals leaching and sludge suspension separating under the action of microbial metabolites. Each of the phases (sediment and bioextract) can serve as a fertilizer after procedure of additional stabilization. The fertilizers obtained satisfy the EU limits for the materials of agricultural utilization. The vegetation experiments have shown that the fertilizer application results in tenfold increase of plant harvest and provides high quality of target product.

Key words – sludge solids, sewage sludges, utilization, agricultural, bioleaching, heavy metals.

I. Introduction

Widespread biological municipal wastewater treatment leads to the formation and storage of huge amounts of sewage sludges. There are over 7 million tons of dry sludge solids produced per year in the USA, 1.8 million tons in Ukraine, 0.5 million tons in Poland [1]. Therefore, the reducing sewage sludge volume and its utilization is a problem facing many communities.

Over the years, the main methods of disposal sludge wastes were landfilling, incineration and ocean dumping [2, 3]. The disadvantages of these sludge sediments handlings are high cost, secondary environmental pollution. Thus, they are ecologically unacceptable. Therefore at present other ways of sludge wastes utilization are being developed: production of building materials, biofuel, activated carbon, electric power, as well as fertilizer for agriculture [3, 4]. Undoubtedly, the last one is the most promising and prospective.

Sewage sludges content plant-essential nutrients, including nitrogen, phosphorus, potassium, vitamins, aminoacids and organic matter in concentrations comparable to commercial fertilizers [5]. Also, sludge solids contain heavy metals (HMs). In appropriate concentrations they are the essential microelements for plant growth, but in high concentrations they are toxic. The presence of all mentioned above beneficial substances stipulates the value of the sewage sludge as a fertilizer for soil quality enhancement. Depending on the density of population and industrial activity of regions, the amounts of heavy metals (microelements) in sewage sludges can vary quite considerable and substantially exceed the maximum permissible concentrations. So, the main obstacle for sludge solids application as a fertilizer is heavy metals excess. The HMs removing from sewage sludge is realized mainly as a chemotrophic termophilic bioleaching [6]. Shortcomings of this method are long duration (up to one month), strong acidification of the medium and additional energy consumption.

Thus, the purpose of our research was to study a possibility of detoxication of municipal sludge wastes, contaminated by heavy metals, and to develop a “green technology” of their rational utilization as a fertilizer.

II. Materials and Methods

The object of this study was sludge wastes as a suspension stabilized (secured from pathogens) in aerobic and anaerobic conditions. The sludge suspension is an aggregatively stable natural biocolloidal system with a solid phase concentration of 25 g/L. Sludge samples from municipal wastewater treatment plant (located in the region of Kyiv, Ukraine) were sampled in jars and kept at 4ºC until use.

A 100-mL sample of sludge suspension (at solid to liquid phase ratio S : L = 1 : 10) was amended with 8 g/L of sodium acetate as a source of carbon and energy for heterotrophic sludge microbiota growth and placed in a 250-mL conical flask. The flask was incubated in a shaker at 228 rpm and 22–24°C. The pH value increased from 6.9 – 7.0 to 8.9 – 9.2 and stabilized after 24 h of exposure. The obtained starter biomass was used for speeding up the processes of HMs bioleaching.

For HMs removing from the sludge solids the method of bioleaching was used. This method was based on target regulation of heterotrophic sludge microbiota vital activity by adding necessary nutrients. A sodium acetate was added as a source of carbon and energy and provided alcaligeneous vector of metabolism.

Three replicates of 100-mL sludge suspension (at solid to liquid phase ratio S : L = 1 : 10) were placed into 250-mL conical flasks, inoculated with 5 % of the corresponding starter culture, amended with 8 g/L of sodium acetate, and incubated as described previously until a constant pH value.

Sludge suspensions after bioleaching procedure were separated on liquid and solid phases which were used in further experiments.

Concentration of metals (Cu, Zn, Mn, Co, Pb, Ni, Cr) in supernatant was determined by the atomic absorption and X-ray fluorescence methods. The methods are detailed described in [7]. The total metals content in sludge solids was analyzed similarly after burning in muffle furnace at 600ºC and dissolution in a mixture of concentrated acids at heating.

The ratio of the mineral and organic components in sludge solids (initial and after bioleaching) were determined by the weight loss after the samples burning at 600°C.

Enterobacteria content as a direct indicator of pathogen level was calculated after seeding on agarized Endo medium.

The quality of the biomineral fertilizer was demonstrated in vegetation experiments. Sweet basil (*Ocimum basilicum*) was selected to study the influence of the fertilizer on plant growth in the pots. During the experimental period the temperature varied between 20 and 25°C. The pots with plants watered daily as required. Fresh sod-podzolic soil was placed in every pot. No fertilizer was added to the control sample. In experimental ones the fertilizer at an application rate of 4 % (weight of dry matter / weight of soil) was added. Its effect on the growth and plants yield over a period of 3 weeks was analyzed by weighting raw herbs and measuring the length of the roots by Root Elongation Test [8] after release from soil and washing.

The plant samples were washed thoroughly with distilled water and dried at 65°C to constant weight. Obtained dry biomass grinded into a powder and burned in the muffle furnace at 500°C. The ash was dissolved in 1M nitric acid and HMs concentration in solution was analyzed as described above.

All experiments and controls were performed in triplicate to ensure that the data were statistically reliable.

III. Results and Discussion

Characteristics of the initial sewage sludge are represented in Table 1. One can see that the sludge solid under study exceeded EU limits as to some parameters which were analized.

TABLE 1

THE CHARACTERISTICS OF THE INITIAL SEWAGE SLUDGE

Parameter	Content	
	Sludge solids	EU limits*
Heavy metals, µg/g		
Cu	1800	1000
Zn	2700	2500
Mn	2400	2000
Co	90	100
Pb	160	750
Ni	110	300
Cr	620	1000
Enterobacteria, PFU/g	220	< 100
Organic matter, %	52	> 40

Note: *EU limits according to [10]

The process of growth of heterotrophic biocenoses of sludge suspension at alcaligeneous vector of metabolism resulted in HMs bioleaching, increase in content of ecologically beneficial microorganisms and organic matter in solid phase, redistribution of heavy metals between solid and liquid phases, effective flocculation, flocks sedimentation following by separation of sludge suspension and sludge solids concentration [10, 11].

The HMs solubilization activity varied from 84 % (Zn) up to 14 % (Cr) and corresponded to the following series: Zn > Mn > Cu > Ni > Co > Pb > Cr. In special studies we have found that similar results can be obtained when used chopped grass meadow as a carbon source for initiation of HMs bioleaching process. It should be stressed, that the efficiency of HMs removal from sludge under the action of heterotrophic sludge microorganisms was close to that in the known method of metals bioleaching with chemoautotrophic sulfur metabolizing sludge biocenoses [6].

The final products of HMs bioleaching after flocks sedimentation and flocculating sludge suspension separation were sediment with ≈ 95 – 99 % huimidty and liquid phase (bioextract). The sludge concentrate is a biomineral fertilizer of prolonged action with immobilized bioelements (as insoluble or slightly soluble salts and complexes) and organic matter content up to 65 %. The bioextract with stable harmless HMs hydroxycarbonate ultracolloidal complexes also can be used as a liquid fertilizer.

The obtained sludge sediments were additionally stabilized (secured from pathogens) in such a way: the pH increasing to 10.0 – 11.0 by dry KOH, exposuring during 4 hours, neutralizing (if it is necessary) to pH = 8.0 by H_3PO_4 and drying up to humidity value from 40 to 60 %. As it is known [12], the fertilizers with alkaline pH is favorable for the formation of waterstable aggregates which are the soil fertility indicator.

The results of these investigations were the basis for “green technology” of bioconversion of municipal sludges into fertilizers. Its scheme is shown in Fig. 1. Thus, two types of fertilizers were obtained: 1 – on the base of solid phase, 2 – on the base of bioextract.

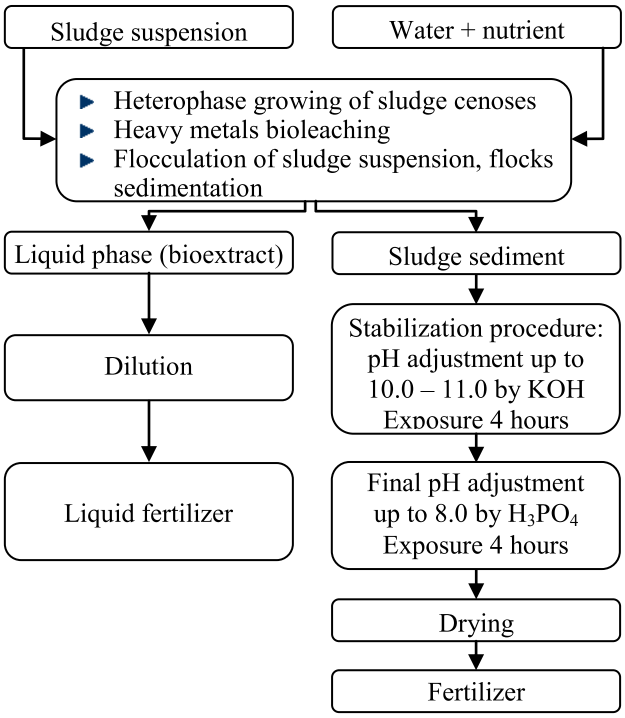

Fig. 1. Scheme of process of bioconversion of sewage sludge into fertilizer

The composition of the fertilizer on the base of sludge solid phase is shown in Table 2. In general, it meets heavy metals, organic matter and pathogens requirements according to [9]. Despite of rather high Cr and Pb residual concentrations, these metals are unavailable to plants because of extremely high values of stability constants of their complexes and salts.

TABLE 2

CHARACTERISTICS OF THE BIOMINERAL FERTILIZER

Parameter	Content	
	Sludge solids	EU limits*
Heavy metals, μg/g		
Cu	630	1000
Zn	442	2500
Mn	1100	2000
Co	54	100
Pb	134	750
Ni	88	300
Cr	533	1000
Enterobacteria, PFU/g	90	< 100
Organic matter, %	65	> 40

There are heavy metals in slightly soluble or unsoluble forms as phosphates, sulphates, carbonates, hydroxides and so on, in sludge solids [13]. Under the influence of organic acids excreted by growing plants, the sludge bioelements can be gradually released from immobilized state into environment and absorbed by [14].

The obtained biomineral fertilizer with prolonged action was assayed in vegetation experiments. The results of the plant growth are shown in Fig. 2. The fertilizer application provides a faster growth of basil plant and increase harvest of 10 times as compared with control (unfertilized) soil.

Fig. 2. Effect of the fertilizer application on sweet basil plant growth. (1) control, unfertilized soil; (2) soil sample with the sludge fertilizer

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To assess the toxicity of the fertilizer environmental biomonitoring Root Elongation Test was used. The toxic effect was not detected by the test. The application of the fertilizer does not lead to a reduction of the stem and root lengths but rather increases these parameters by 130 % and 280 % respectively in comparison with plant grown in control (unfertilized) soil (Fig. 3). Besides, there were no phytoftoroz (blight) symptoms in plants grown, both in control and fertilized soil samples.

Fig. 3. Effect of the fertilizer on plant growth in sod-podzolic soil. Designations are the same as in Figure 2

We have compared the heavy metals content in the basil plant grown in fertilized and unfertilized soils samples with the HMs content in the plant according to the suitable safety standards as determined by the Maximum Permissible Concentrations (Table 3). The results obtained show the food safety of the target plant. Thus, the fertilizer obtained by our technology is ecologically friendly, provides the increase of agricultural products harvest and rational utilization of municipal sludge wastes.

TABLE 3

THE CONTENT OF HEAVY METALS IN THE SWEET BASIL PLANT

Metal	Content of metal, μg/g of dry weight		MPC*, μg/g of dry weight
	Growth on control soil	Growth on soil with fertilizer	
Zn	25.07	35.80	50.00
Cu	9.02	13.40	20.00
Pb	0.60	0.84	1.00

Note: * MPC - Maximum Permissible Concentrations on the basis of the National Food Standards according to [15]

Conclusion

The process of HMs bioleaching from sewage sludge by enhancing vital ability of heterotrophic sludge microorganisms at alkaline vector of metabolism was studied. The results of the process were effective flocculation, flocks sedimentation following by separation of sludge suspension into liquid (bioextract) and solid phases, redistribution of heavy metals between them. Each of the phases can serve as a fertilizer. The fertilizer on the base of solid phase satisfy the EU limits for land application and can provide a tenfold increase of target plant harvest of high quality.

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