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Letter to Editor

Heavy Metals Removal in the Mechanical-Biological Wastewater Treatment Plant "Wschód" in Gdańsk

E. Kulbat, K. Olańczuk-Neyman*, B. Quant, M. Geneja, E. Haustein

Hydro- and Environmental Engineering Faculty, Gdańsk University of Technology
ul. Narutowicza 11/12, 80-952 Gdańsk, Poland

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Abstract

Heavy metals removal from municipal wastewater has been studied. This paper presents results of investigations carried out in 2000-2001. The investigations concerned analysis of wastewater and sewage sludge from the wastewater treatment plant "Wschód" in Gdańsk, where the modified system UCT (MUCT) is used. It was indicated that the concentrations of seven heavy metals (Zn, Cu, Pb, Cd, Cr, Ni, Ag) in wastewater were rather low. After treatment, the metals concentration met criteria given in the Regulation of the Minister of Environmental Protection of Aug.1, 2002, that was valid at the time of the investigations. Analysis of effectiveness of metals removal during wastewater treatment processes undoubtedly indicates the fundamental role of biological treatment stage in metals removal.

Analysis of heavy metals concentrations in primary and biological sludge have proved that the sludge from the WWTP "Wschód" can be utilized in land-farming and land reclamation (according to the Regulation of the Minister of Environmental Protection of Aug.1, 2002).

Keywords: wastewater treatment plant, heavy metals, sludge, biological sludge

Introduction

Heavy metals are removed from raw sewage in physical and chemical treatment processes such as sedimentation with suspended solids and activated sludge flocs, co-precipitation by organic compounds and chemical precipitation, as well as in microbiological processes. Contribution of various processes in heavy metals removal depends on: applied technology of wastewater treatment, type and concentration and oxidation state of metal, composition and pH of wastewater, type of microorganisms [1] and mechanism of metal removal [2]. Heavy metals can be actively bound by living microorganisms by means of the following mechanisms: intracellular accumulation, extracellular precipitation and chemical transformations catalyzed by these microorganisms, such as oxidation, reduction, methylation, demethylation. Passive mechanisms of metal binding are as follows: extracellular complexation of metal by substances excreted by cells and biosorption - binding of heavy metals to active groups of chemical compounds of cell walls and membranes [3,4].

Nowadays, any publications presenting studies on effectiveness of metal removal in wastewater treatment processes are hardly available. Oliver & Cosgrove [5] and Obarska-Pempkowiak [6] report that about 50% of zinc, 60% of copper, 79% of lead, 80% of cadmium and 1% of nickel are removed by wastewater treatment plants.

Despite the fact that according to Directive 76/464/EU, metals and metal compounds belong to group II of substances extremely dangerous for water environment, heavy metals are not included in the new Polish Regulation of the Minister of Environmental Protection of Nov.29, 2002 (although they were defined in the former Regulation).

*Corresponding author

This paper presents the results of two years (2000-2001) investigations on heavy metals removed from sewage. The investigations were performed in wastewater treatment plant (WWTP) "Wschód" in Gdańsk, where a multiphase activated sludge system co-operates with a system for volatile fatty acids (VFA) generation from primary sewage sludge. The investigations were carried out in close co-operation with the operator of the facility: Saur Neptun Gdańsk. The aim of this study is to alnalyze the effectiveness of heavy metals removal at subsequent stages of wastewater treatment and evaluation of their concentrations in the effluent in relationship to obligatory Polish Regulations. The concentrations of heavy metals in sewage sludge generated in the plant are also estimated.

Materials and Methods

The Study Area

The wastewater treatment plant "Wschód" in Gdańsk receives about 90,000 m^3 of municipal sewage per day. The wastewater inflowing to the plant contains domestic and industrial sewage, e.g. from food production (fish, dairy and meat processing), gas and electrochemical, as well as chemical industries.

Recently, the plant underwent modernization in order to secure highly-effective removal of organic and nutrient pollutants from sewage that is discharged to the coastal waters of Gdańsk Bay. In November 1999 the start-up and preliminary operation period were completed. The scheme of the process line of the WWTP after modernisation is presented in Fig.1.

Mechanical treatment units are typical and consist of mechanical screens, aerated sand traps with grease removal traps and radial-flow primary clarifiers. The plant is equipped with a three-chamber fermenter. Pre-fermented sludge is discharged back to the influent to primary clarifiers.

The biological treatment unit consists of 6 multiphase MUCT (modified UCT system) reactors and 12 radial-flow secondary clarifiers. Denitrification of nitrates takes place in two chambers. The second of the denitrification chambers can optionally work as anoxic or aerobic. Such solution allow an increase in the nitrification volume of the bioreactor when the rate of ammonia nitrogen oxidation is low. The mixture of activated sludge and sewage, recirculated from the nitrification chamber is deoxidated in deaeration chamber before it enters the denitrification chamber.

Methods

Investigations of sewage were carried out in the period of two years from 2000 to 2001. The mean daily samples of raw sewage after screens (sampling point A1s), mechanically treated sewage (sampling point B2s) and finally treated sewage (sampling point Cs) were collected for physical and chemical analyses. In 2001 the raw

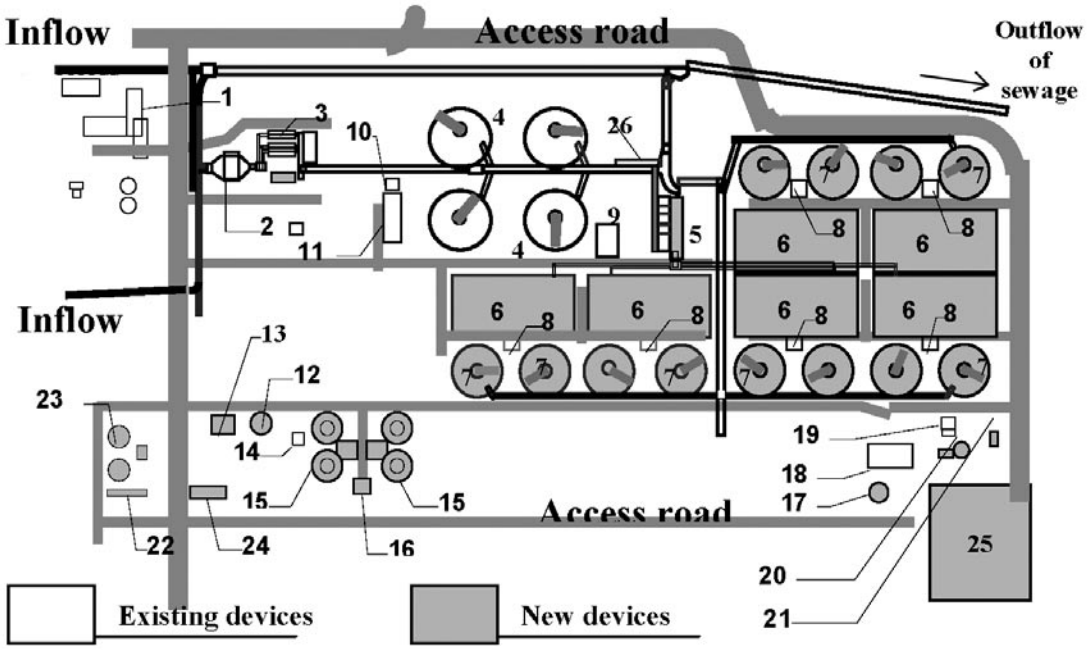

Fig. 1. Scheme of the process line of WWTP "Wschód" in Gdańsk.
1 – Dispatch office, 2 - Screens, 3 – Sand trap, 4 – Primary clarifiers, 5 – Intermediate pumping station, 6 – Biological reactors, 7 – Secondary clarifiers, 8 – Recirculated and excess sludge pumping station, 9 - Blowers, 10 – Raw sludge pumping station, 11 – Raw sludge fermenter, 12 – Operation tank, 13 – Excess sludge thickening station, 14 – Mixed sludge pumping station, 15 - Sludge digestion chambers, 16 – Digested sludge pumping station, 17 – Digested sludge container, 18 – Sludge dewatering station, 19 – PIX containers and installation for PIX dosing, 20 - Sludge waters treatment equipment, 21 – Waste removers discharge point, 22 – Biogas contaminations separator, 23 – Biogas reservoirs, 24 – Gas-oil-fired boiler plant, 25 – Temporary sludge disposal site, 26 - Storm overflow.

Table 1. The average concentrations of metals in raw sewage, in mechanically treated sewage and in the effluent.

Type of sewage	Parameter	Metal mg/dm^3						
		Zinc	Copper	Lead	Cadmium	Nickel	Chromium	Silver
2000								
raw	average value	0.30	0.07	0.02	< 0.01	0.01	0.02	0.01
	standard deviation	0.20	0.04	0.01	< 0.01	0.01	0.02	0.02
mechanically treated	average value	0.23	0.10	0.02	< 0.01	0.02	0.03	0.00
	standard deviation	0.13	0.15	0.02	< 0.01	0.01	0.04	0.01
effluent	average value	0.09	0.00	0.00	< 0.01	0.01	0.01	0.00
	standard deviation	0.12	0.00	0.00	< 0.01	0.01	0.01	0.00
2001								
raw	average value	0.27	0.06	0.01	< 0.01	0.02	0.02	0.01
	standard deviation	0.11	0.06	0.01	< 0.01	0.01	0.01	0.00
mechanically treated	average value	0.24	0.06	0.01	< 0.01	0.02	0.02	0.01
	standard deviation	0.17	0.05	0.01	< 0.01	0.01	0.01	0.00
effluent	average value	0.05	0.01	0.01	< 0.01	0.02	0.01	0.01
	standard deviation	0.09	0.02	0.01	< 0.01	0.01	0.01	0.00

sludge from primary clarifiers (sampling point B1o) and raw biological sludge from secondary clarifiers (sampling point Co) were also investigated. The samples were collected once a month.

Concentrations of the following metals were analyzed in the samples of sewage and sludge: zinc, copper, lead, cadmium, nickel, chromium and silver.

Determinations of heavy metals concentrations were carried out without preliminary separation of total suspended solids. The samples of sewage, of the volume of 250 cm^3, were evaporated to dryness and complemented with 0.1 mol/dm^3 nitric acid to adequate volume. The samples of sludge were dried to constant weight and mineralized with aqua regia. Mineralization was performed using mineralizator DK 6/TMD 6 produced by Velp Scientifica. Mineralization time was 120 minutes.

The concentrations of metals were performed using atomic absorption spectrometer Vario 6 produced by Analytik Jena and hollow cathode lamps.

Investigations Results

Concentrations of five heavy metals: lead, cadmium, nickel, chromium and silver in raw sewage inflowing to WWTP "Wschód" in the period from January 2000 to December 2001 varied from about 0.01 mg/dm^3 to a few hundreth parts. However, concentrations of zinc and copper were substantially higher: in 2000 (the first year after modernization of the plant) the concentrations of these two metals varied from 0.02 to 0.64 mg Zn/dm^3 and from 0.01 to 0.16 mg Cu/dm^3, respectively and in 2001 they varied from 0.18 to 0.51 mg Zn/dm^3 and from 0.02 to 0.19 mg Cu/dm^3. Similar proportions between the ranges of fluctuations of zinc and copper and ranges of concentrations of the other five heavy metals were also noted in mechanically treated sewage and in the effluent. The ranges of concentrations of heavy metals and average concentrations of metals in wastewater are presented in Table 1. Analysis of these data undoubtedly proves that the highest decrease of zinc and copper concentrations in sewage takes place after the biological treatment stage, though zinc is partly removed during mechanical treatment (from 0.3 to 0.23 mg/dm^3 in 2000 and from 0.27 to 0.24 mg/dm^3 in 2001). Fluctuations of other metals concentrations (lead, chromium, nickel, silver and cadmium) in the treatment processes were insignificant.

Fluctuations of zinc and copper concentrations in the years 2000 and 2001 are presented in Fig.2. During the first year of investigations (2000) concentrations of these metals varied in the higher range, especially in sewage after subsequent stages of treatment. In 2001 the fluctuations of zinc and copper concentrations in mechanically treated sewage and in the effluent were smaller, probably because that operation of the plant became more stable and also due to smaller fluctuations of concentrations of these metals in inflowing sewage.

Concentrations of four out of seven analyzed heavy metals, viz. zinc, copper, lead and cadmium were higher in primary sludge than in biological sludge. The highest differences (about 30%) were observed in the case of lead and cadmium while the smallest difference (about 8%) was noted in the case of zinc. In contrast, the average

concentrations of other metals, viz. nickel, chromium and silver were higher in excess sludge (by 31.0%, 7.7% and 20.7%, respectively).

Concentrations of analyzed metals in sludge decreased in the following order:
in primary sludge:

Zn>Cu>Cr>Ag>Pb>Ni>Cd

in biological sludge:

Zn>Cu>Pb>Cr>Ag>Ni>Cd

Discussion of Results

Average concentrations of all analyzed metals in raw sewage from the WWTP "Wschód" in Gdańsk in the years 2000 and 2001 were lower than average concentrations for municipal wastewater in Poland and from the values reported by foreign authors [2,8]. Thus, relatively, pollution of sewage inflowing to the plant with heavy metals is relatively low.

Average loads of metals inflowing to the plant with raw sewage in the years 2000 and 2001 are presented in Table 3.

The daily load of zinc is the highest among the analyzed metals (e.g. it is 4 times higher than the load of copper, over 10 times higher than the load of chromium and 15-20 times higher than the load of lead). In 2001, average loads of zinc, copper, nickel and silver in raw sewage were higher than in 2000 (by approximately 14%, 8%,

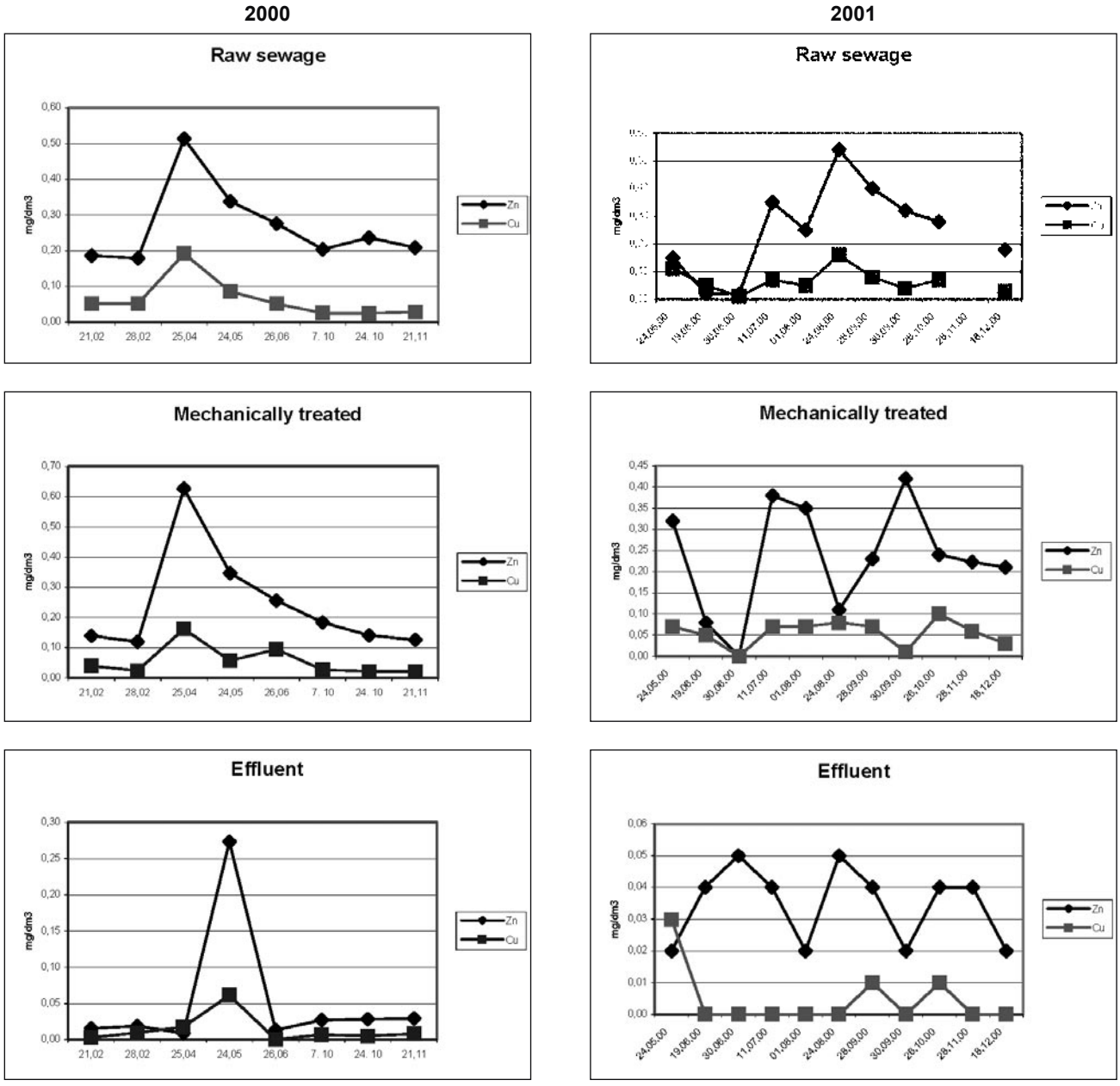

Fig. 2. The fluctuations of zinc and copper concentrations in raw sewage, mechanically treated sewage and in the effluent in 2000 and 2001. Average concentrations of metals in sewage sludge in 2001 are presented in Table 2.

Table 2. Average concentrations of heavy metals in sewage sludge from WWTP "Wschód".

Type of sewage sludge	Parameter	Metal mg/kg d.m.						
		Zinc	Copper	Lead	Cadmium	Nickel	Chromium	Silver
primary	average value	702.5	229.5	43.2	4.8	39.0	54.7	45.0
	standard deviation	357.8	147.2	3.6	4.1	10.2	27.2	10.1
biological	average value	757.8	267.1	56.1	6.2	29.8	50.8	37.3
	standard deviation	215.4	71.9	23.0	3.7	12.4	12.9	9.4

Table 3. The average daily loads of metals in sewage inflowing to the WWTP "Wschód".

Year	Loads of metal g/d						
	Zinc	Copper	Lead	Cadmium	Nickel	Chromium	Silver
2000	20079	5265	1230	< 900	857	1638	434
2001	23259	5698	924	< 900	1872	1560	746

Table 4. The average reduction of metals concentrations in subsequent stages of wastewater treatment.

Stage of wastewater treatment	Metal						
	Zinc	Copper	Lead	Cadmium	Nickel	Chromium	Silver
year 2000							
mechanical	7.1%	17.2%	9.1%	-	1.5%	25.1%	16.7%
mechanical-biological	86.2%	93.2%	83.0%	-	1.5%	66.7%	66.7%
year 2001							
mechanical	9.6%	12.1%	18.1%	-	3.7%	7.0%	5.3%
mechanical-biological	80.7%	78.1%	48.0%	-	17.3%	45.3%	28.3%

54% and 42%, respectively), while the average loads of lead and chromium were higher in 2000 (by 25% and 5%, respectively).

A significant correlation between fluctuations of zinc and copper concentrations in treated sewage in 2001 was discovered. The correlation coefficient was equal to 0.93 for raw sewage, 0.93 for mechanically treated sewage and 0.96 for the effluent. In 2000, during the plant start-up period, the heavy metals concentrations fluctuated within a wide range and no correlations or season changes were observed.

In Table 4 the percentage reduction of heavy metals concentrations during sewage treatment processes are presented.

The effectiveness of heavy metals removal from sewage was high, with an exception of cadmium. Generally, in 2000 the reduction of metals concentrations in wastewater treatment processes were higher than in 2001. The average reduction rates in 2000 and 2001 were as follows: for zinc 86.2% and 80.7%, for copper 93.2 and 78.1%, for chromium 66.7% and 45.3%, for silver 66.7% and 28.3%, and for lead 83% and 48%. These values are higher than reported in literature [5,6].

The results presented in Table 4 indicate that the share of mechanical treatment in metal removal is small (from 1.5% to 25%) and different for various metals. This results from different sorption capacity of metals as well as from different susceptibility to chemical precipitation and removal by microorganisms.

Biological treatment processes are of great importance in removal of metals from sewage. The part of these processes in metals removal from sewage in the WWTP "Wschód" is presented in Table 5.

In biological treatment processes the concentrations of metals decreased by over 80% (with the except of chromium – 74.9% in 2000). An insignificant part of mechanical treatment probably results from low concentrations of analyzed heavy metals in raw sewage.

The concentration of all analyzed metals in treated sewage did not exceed the obligatory values for sewage discharged to water or soil given in the former Regulation of the Minister of the Environment, Natural Resources and Forestry of Nov. 5, 1991. According to the new Regulation of Nov. 29, 2002 the admissible concentrations of heavy metals in municipal sewage are not limited.

Due to the toxic effect on organisms and the ability of cumulating in the environment, the concentration of heavy

Table 5. The part of biological treatment processes in metals removal in the WWTP "Wschód".

The contribution of biological treatment processes in metals removal [%]						
Zinc	Copper	Lead	Cadmium	Nickel	Chromium	Silver
year 2000						
92.9%	82.8%	90.9%	-	98.5%	74.9%	83.3%
year 2001						
90.4%	87.9%	81.9%	-	96.3%	93.0%	94.7%

Table 6. The comparison of heavy metals concentration in sludge from the WWTP "Wschód" in Gdańsk and the admissible values defined in the Regulation of the Minister of Environmental Protection.

Type of sewage sludge	Metal mg/kg d.m.						
	Zinc	Copper	Lead	Cadmium	Nickel	Chromium	Silver
primary	702.5	229.5	43.2	4.8	39.0	54.7	45.0
biological	757.8	267.1	56.1	6.2	29.8	50.8	37.3
Admissible values according to Regulation*	2500	800	500	10	100	500	---

*) the concentrations admissible for sludge utilized in land-farming and land reclamation (the Regulation of the Minister of Environmental Protection of Aug. 1, 2002)

metals in sewage sludge is one of the basic indicators of sludge quality in the aspect of its possible application in land-farming. According to Kabata-Pendias and Pendias [10], the elements capable of soil pollution are cadmium, copper, mercury, lead, zinc, chromium and nickel. These metals adsorb on the surface of soil profile and thus can accumulate in the plants.

It was indicated that average concentrations of seven analyzed metals viz. zinc, copper, lead, chromium, nickel, cadmium, silver in raw and excess sewage sludge generated in WWTP "Wschód" do not exceed the admissible values given in the Regulation of the Minister of Environmental Protection of Aug. 1, 2002. The concentration of all analyzed metals in the sludge are lower than the most rigorous values regarding sludge utilization in land-farming and for land-reclamation. The comparison of the obligatory values with the concentrations measured in the sludge from WWTP "Wschód" are presented in Table 6.

Conclusions

In the paper it was indicated that the concentration of the seven analyzed heavy metals (Zn, Cu, Pb, Cd, Cr, Ni, Ag) in municipal wastewater inflowing to WWTP "Wschód" were not high. After treatment, the metals concentration met criteria given in the Regulation of the Minister of Environmental Protection of Aug. 1, 2002, that was valid at that time. Analysis of the effectiveness of metals removal during wastewater treatment processes undoubtedly indicates the fundamental role of the biological treatment stage in metals removal.

Another issue was the quality of sewage sludge generated in the WWTP. Analysis of heavy metals concentrations in primary and biological sludge indicates that the sludge from WWTP "Wschód" can be utilized in land-farming and land reclamation (Regulation of the Minister of Environmental Protection of Aug. 1, 2002). It should be stressed however, that the Regulation also defines the maximal admissible concentrations of metals in soils fertilized with municipal sludges as well as maximal admissible loads of municipal sludges. Moreover, prior to the decision of utlizing sludge from the WWTP "Wschód" in land-farming, the sanitary condition of sludges should be considered.

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