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HEAVY METAL CONTAMINATION OF ORGANIC SLUDGES

The influent to municipal wastewater treatment plants contains significant amounts of heavy metals. Most of the insoluble metal hydroxides tend to be removed by sedimentation or adsorption to the activated sludge. During stabilization of the excess sludge the concentration of inert metal hydroxides increases since the amount of organic material decreases. This paper defines an "accumulation factor" that is the ratio of the metal content in the sludge and the amount of metal removed from the influent. A reasonable estimate for the accumulation factor is 10.000.
This paper also compares several guidelines for the use of municipal sludge as a fertilizer. The allowable annual loadings based on heavy metals is in Europe lower than in the U.S. The allowable lifetime load of metals does not differ that much.

1. INTRODUCTION

The heavy metal content of organic sludges from municipal treatment plants should be kept under control, in order not to interfere with the ultimate disposal method. Especially with land disposal of the excess sludge as a fertilizer, it is important to limit the metal content to prevent the build-up of the metals in the food chain to untolerable limits. Also with incineration as the ultimate disposal method is the heavy metal content of importance. Part of the low boiling metals will leave the incinerator in the air and return to earth in rainfall.

The influent to every municipal treatment plant contains heavy metals. Part can originate from industrial discharges, but even residential municipal wastewater contains significant concentrations of metals.

This paper will analyze the quantities of metals retained in a treatment plant and what the resulting metal concentration in the sludge is. The increase in metal content is expressed by an "accumulation factor" that indicates the metal content in the dry digested sludge (in ppm) per ppm of metal removed from the influent.

Once the accumulation factor is determined it is possible to establish target concentrations for heavy metals in the influent to the treatment plant so that the metal will not accumulate to such levels that it restricts the application of the sludge as a fertilizer. The accu-

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mulation factor can also be useful for monitoring purposes to predict what the metal concentration in the sludge will be a few weeks later once some information is available on the amount of metals removed in the treatment process. This will allow some planning ahead instead of analyzing the digested sludge when it is ready for land disposal.

2. TYPICAL METAL CONCENTRATION IN MUNICIPAL WASTEWATERS AND PERCENTAGE REMOVAL IN BIOLOGICAL TREATMENT PLANTS

A large volume of literature is being published reporting on heavy metal concentrations in the influent to municipal treatment plants and the percentage retained by biological treatment. Although the individual data vary over a wide range it is possible though to detect certain trends. It is well documented that even residential communities will discharge wastewater that contains significant amounts of heavy metals. Table 1 lists some of the typical concentrations found in this type of wastewater.

Table 1

Heavy metal concentration in residential municipal wastewater

Stężenia metali ciężkich w bytowo-gospodarczych ściekach miejskich

Community	Ref.	Metal conc., mg/dm^3					
		Cu	Zn	Cr	Ni	Pb	Cd
Muncie, Ind.	[1]	0.12	0.25	0.008	0.024	0.11	0.007
New York, N.Y.	[8]	0.21	0.25	0.09	0.09	—	0.019
Pittsburgh, Pa.	[8]	0.12	0.20	0.022	0.014	0.075	0.013
Jefferson City, Mo.	[4]	0.097	0.29	0.14	—	0.12	0.015
Grand Island, Neb.	[4]	0.17	0.35	0.059	—	0.16	0.018
Sioux City, Iowa	[4]	0.10	0.39	0.12	—	0.15	0.023
New York, N.Y. (range of values)	[17]	0.11—0.33	0.13—0.37	0.003—0.15	0.01—0.15	— —	0.001—0.007

Communities receiving industrial wastewater can have higher concentrations of metals in the influent. Pretreatment requirements are in effect in most communities these days and it is rare that completely untreated industrial wastewaters are allowed to enter the sanitary sewers. The effect of a pretreatment program in Grand Rapids, Michigan can be illustrated by data presented in table 2.

These data show the reduction in the discharge of heavy metals to the municipal treatment plant with time. The largest reduction was experienced during the early phases of the implementation of a pretreatment program. In the last couple of years the mass input levels off and it is anticipated that any further reductions will be less dramatic.

Table 3 shows reported heavy metal concentrations in a variety of municipalities. The wastewater includes industrial discharges and probably also a larger portion of non-

Table 2

Heavy metal concentrations in the influent to the municipal treatment plant of Grand Rapids [1]

Stężenia metali ciężkich w dopływie do miejskiej oczyszczalni ścieków w Grand Rapids [1]

Year	Metal conc., mg/dm^3			
	Cu	Zn	Cr	Ni
73–74	0.5	1.2	0.4	0.5
72–73	0.4	3.5	1.1	0.8
71–72	0.6	3.8	0.9	0.9
70–71	1.0	2.5	1.6	1.6
69–70	1.3	3.4	2.4	2.0
68–69	2.1	3.7	4.5	2.4
67–68	2.8	—	5.1	3.2

Table 3

Heavy metal concentrations in several municipalities

Stężenia metali ciężkich w niektórych ośrodkach miejskich

Municipality	Ref.	Metal conc., mg/dm^3					
		Cu	Zn	Cr	Ni	Pb	Cd
Muncie 1972	[7]	0.25	0.79	0.27	0.10	0.92	—
Muncie 1973	[8]	0.26	1.15	0.24	0.14	0.93	—
Grand Rapids 1974	[1]	0.5	1.2	0.4	0.5	—	—
Pittsburgh 1973	[8]	0.13	0.65	0.095	0.078	0.12	0.021
New York Area	[20]						
Median		0.10	0.18	0.05	0.10	0.20	0.02
95% value		0.85	1.14	0.45	0.50	0.20	0.04
Burlington	[21]						
Total		0.31	2.4	0.29	0.33	0.23	0.006
Dissolved		0.17	0.57	0.02	0.22	0.012	0.001
Dallas, Tx	[10]	0.092	0.32	0.22	0.073	0.095	0.013
New York	[17]						
Avg.		0.27	0.41	0.16	0.11	—	0.016
(range of 12 plants)		0.13–0.34	0.27–0.80	0.04–0.50	0.05–0.31	—	0.005–0.050

point sources like stormwater than the data tabulated in table 1. A comparison is difficult, but the data show that the concentrations for all metals are somewhat higher than in pure residential wastewater. Especially the data presented for New York, Pittsburgh and Muncie provide a good comparison between residential wastewater and the influent to the municipal treatment plant. The concentration for zinc, chromium and nickel are especially higher in the combined influent.

The removal of the heavy metals from the influent will depend in what form the metal is present. In general most of the insoluble material will be either removed in the primary clarifier or will adsorb to the activated sludge floc during secondary treatment. The soluble metal should be removed to a lesser extent. It is unfortunate that only very few authors report their findings by differentiating between the soluble and insoluble fraction. Some typical removal percentages for the different kinds of heavy metals are presented in table 4.

Table 4

Typical removal percentages of heavy metals in biological secondary treatment plants
Typowe procenty usuwania metali ciężkich w oczyszczalniach biologicznych

Community	Ref.	Metal, % removal					
		Cu	Zn	Cr	Ni	Pb	Cd
Survey of Several Cities	[6]	0–70	35–80	40–80	15–40	50–90	20–45
Dallas	[10]	33	65	57	21	56	39
Burlington	[21]						
Total		71–73	77–78	79–86	16–18	91–93	78–80
Dissolved		59	30	70	1	50	N/D
Cincinnati	[11]						
	range	50–80	74–97	18–58	12–76	—	—
	average	75	89	44	28	—	—
Muncie	[1]	68–77	70–77	78–83	0–36	71–82	—
Grand Rapids	[1]	13–57	35–51	19–66	18–41	—	—
Pittsburgh	[8]	55	63	66	10	80	66
New York (Avg of 12 plants)	[17]	45	36	48	17	—	41
Joplin, Miss.	[4]	65	51	38	—	66	29
Grand Island, Neb.	[4]	61	48	78	—	43	11
Shelby, Ohio	[22]	50–65	80–82	52–72	27–39	—	—

Oliver [21] has published data differentiating betweeen the removal of the soluble and insoluble fraction. It can be seen that high percentages of insoluble metals are generally retained in the treatment plant, while the percentage removal of the soluble fraction is less. Soluble nickel is almost not removed. The other soluble metals are removed for about 50 %.

Generalizing it seems reasonable to state that most metals are removed for about 60 % except nickel, which is removed for only 30 %. These numbers can serve as a tool for estimating purposes. Specific removal percentages for individual plants can vary widely depending on factors like:

1. Percentage of the metal present in the soluble form.

2. Presence of complexing agents like humic acids that can keep soluble metals in solution.

3. Suspended solids carryover from secondary clarifier. Good clarification will result in a higher percentage removal.

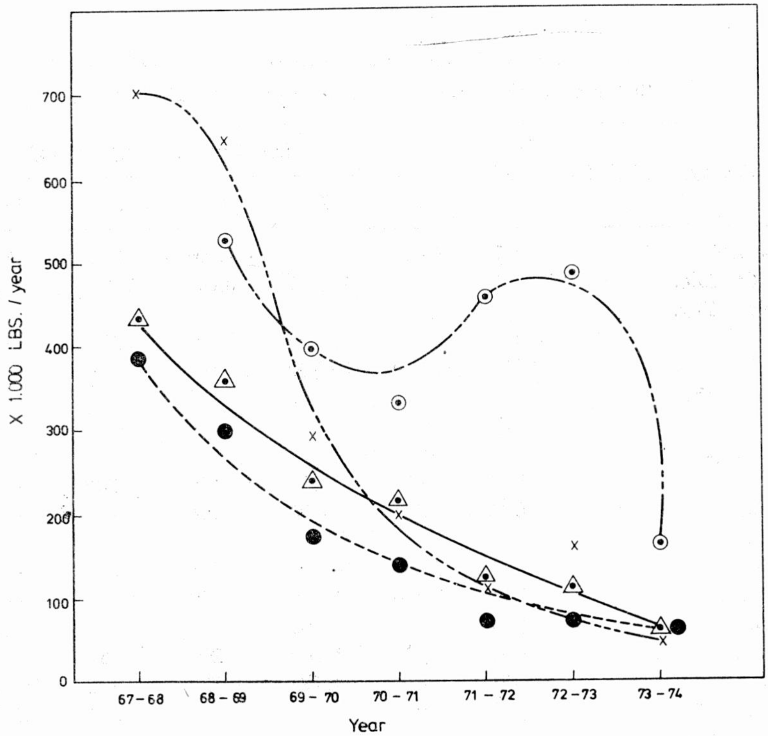

Fig. 1. Heavy metals discharged to treatment plant of Grand Rapids

– •• – ⊙ zinc, ——— △ nickel, – – – – • copper, ——— – – – ——— × chromium

Rys. 1. Zrzut metali ciężkich do oczyszczalni komunalnej Grand Rapids

– •• – ⊙ cynk, ——— △ nikel, – – – – • miedź, ——— – – – ——— × chrom

4. Incoming metal concentration. Percentage removal normally increases with concentration in influent.

5. Operating pH treatment plant.

3. TYPICAL METAL CONCENTRATION IN EXCESS SLUDGE

Heavy metals retained in the treatment plant are concentrated in the excess sludge. No heavy metal retained in the treatment process is destroyed. The metal can be present in several forms. Soluble metal that is retained can either be incorporated in the cell material or form a complex with organic material outside the cell. Insoluble metals will be retained in their insoluble form and are incorporated in the excess sludge.

Typical metal concentrations in municipal sludges are shown in table 5. It shows that one can expect a wide range in the values. For comparison the table also lists metal concentrations in a soil and in cow manure. It is interesting to note that the mean values for several plants for a survey in the U.S. and one in England are very close.

Table 5

Heavy metal concentration in excess activated sludge
Stężenia metali ciężkich w osadzie czynnym nadmiernym

Community and type of sludge	Ref.	Metal conc. (ppm) (mg/kg)					
		Cu	Zn	Cr	Ni	Pb	Cd
Muncie, Digested	[1]	1,450	3,430	1,800	200	8,400	—
Waterbury, Ct, Dig.	[1]	16,000	11,000	8,000	2,400	—	—
Grand Rapids, Dig.							
73–74	[1]	2,500	5,700	2,700	1,700	—	—
67–68	[1]	19,200	27,900	28,800	11,900	—	—
Grand Island, Neb.							
Raw	[4]	450	680	110	—	120	16
Richmond, Ind.							
Digested	[24]	3,000	3,000	3,000	200	—	—
Bryon, O. Dig.	[24]	1,000	11,000	4,000	100	—	—
Rockford, Ill.							
Digested	[24]	2,000	10,000	8,000	500	—	—
Shelby, O. Dig.	[22]	3,200	11,000	3,200	610	—	—
Cayuga Hgts.	[17]	821	560	169	36	136	7
Chicago	[17]	578	1,160	207	51	605	15
Los Angeles	[17]	2,890	4,590	4,925	402	3,065	171
San Francisco	[17]	900	601	1,500	223	2,521	9
Survey of 33 plants in USA							
avg.	[6]	1,230	2,780	1,100	410	830	31
Survey of 42 plants in Eng., mean	[3]	970	4,100	980	510	820	—
Note:							
Soil (typical values)	[15]	5	20	5	5	15	0.3
Cow Manure	[11]	62	71	56	29	16	0.8

For a study conducted for the National Commission on Water Quality [1] several cities were studied in depth and an abundance of data was collected on the fate of heavy metals in a biological treatment plant. This allowed the calculation of a so called "accumulation factor". This factor represents the concentration of a metal in the excess sludge (in ppm) in case 1 mg/dm^3 of the metal in the influent is removed. Of course the accumulation factor will increase with the degree of stabilization of the sludge. During aerobic or anaerobic digestion the organic material is decomposed while the metal hydroxides are generally unaffected. Therefore the ratio between metal hydroxides and organic material will increase.

For a few cities the accumulation factor is calculated and presented in table 6. Although there is a wide spread in the numbers a reasonable estimate for accumulation factor is 10,000 for digested sludge. This means that if the difference between influent and effluent concentration of a metal is 0.5 mg/dm^3 the concentration of that metal in the digested sludge will be about 5000 ppm.

Table 6

Accumulation factors of metals in sludge expressed as mg/kg in dry sludge per mg/dm³ of metal removed from influent (biological treatment plants)

Współczynniki akumulacji metali w osadzie, w mg/kg w suchej masie osadu na mg/dm³ metalu usuniętego z dopływu (oczyszczanie biologiczne)

City		Type of Sludge	Ref.	Accumulation Factor
Kansas City, Mo.		Raw Primary	4	3,330
Kansas City, Ks		Raw Primary	4	3,265
Jefferson City		Raw Primary	4	10,800
Joplin, Mo.		Raw Secondary	4	24,700
Grand Island, Neb.		Raw Secondary	4	3,270
Shelby, Ohio		Raw Secondary	22	11,000
Sioux City, Ia.		Digested Primary	4	9,520
Muncie, Ind.	1972	Digested Secondary	2	9,000
	1973			7,330
Grand Rapids	1967	Digested Secondary	2	18,600
	1974			17,800
Bryan, Ohio		Digested Secondary	24	7,400
Richmond, Ind.		Digested Secondary	24	16,000
Rockford, Ill.		Digested Secondary	24	8,500

4. TARGET METAL CONCENTRATIONS TO ALLOW AGRICULTURAL USE

To avoid problems with heavy metal contamination several agencies have developed guidelines for sludge application rates. The different guidelines developed in the USA, Sweden and Holland are summarized in table 7. It shows that there is a large difference in opinion as to what is acceptable and what is not. This paper is not meant to critically evaluate these guidelines and therefore they are only presented as guidelines in effect at this point in time. As shown in table 5 there are a large number of communities with excess sludge that contain high metal concentrations that can limit the agricultural usage of these sludges.

Table 7

Guidelines for heavy metal concentrations in digested sludge for use as fertilizer

Normy stężeń metali ciężkich w przefermentowanym osadzie do wykorzystania rolniczego

A. EPA [9]

Total cumulative metal loadings that has shown not to cause problems:

Metal	Soil Exchange Capacity (meq/100 g)		
	0–5	5–15	15
	metal load (kg/ha)		
Lead	510	1020	2040
Zinc	255	510	1020
Copper	128	255	510
Nickel	51	102	204
Cadmium	5	10	20

B. **State of Pennsylvania** [19]

	Maximum loading rate kg/ha/yr	Conc[1]. ppm	Lifetime Maximum
Cadium	1.1	50	3.4 kg/ha/yr
Copper	22.5	1000	
Chromium	22.5	1000	
Lead	22.5	1000	
Mercury	0.22	10	
Nickel	4.5	200	
Zinc	45	2000	

[1] Based on load of 22,500 kg/ha/year of dry sludge

C. **Sweden**

Standards for metallic content of dry digested sludge (ppm) (ng/kg), [23]

	Normal digested sludge	Polluted digested sludge	Maximum loading rate[2] kg/ha/yr
Zinc	1000–3000	> 10,000	3
Copper	500–1500	> 3,000	1.5
Lead	100–300	> 1,000	0.3
Chromium	50–200	> 1,000	0.2
Nickel	25–100	> 500	0.1
Cadmium	5–15	> 25	0.015
Merkury	4–8	> 25	0.008

[2] Allowable application rate for normal sludge: 1000 kg of dry solids/yr/ha sludge with high metal concentrations are not allowed to be used for agricultural use.

D. **The Netherlands** [13]

	Preferred metal concentrations	Maximum loading rate[3] cropland	grassland
Zinc	< 2,000 ppm	4	2
Copper	< 500 ppm	1	0.5
Nickel	< 50 ppm	0.1	0.05
Cadmium	< 10 ppm	0.02	0.01

[3] Application rate: 2,000 kg dry matter/yr/ha on cropland
1,000 kg dry matter/yr/ha on grassland.

E. **Guidelines based on maximum cadmium loadings**

EPA [9] 1 to 2 kg/ha/yr
England [25] 5 kg/ha/30 yrs or 0.17 kg/ha/yr
Netherlands [25] 2 kg/ha/100 yrs for cropland
1 kg/ha/100 yrs for grassland
Scandinavia [25] 0.015 to 0.019 kg/ha/yr
Keeney [16] 2,2 kg/yr or 22 kg/ha/lifespan
Ill. EPA [14] 0.34 kg/ha/yr or 6.8 kg/ha/lifespan

F. **Guidelines based on zinc equivalent (Z.E.)**

ZE = (Zn) +2 (Cu)+8 (Ni)
CHUMPLEY [5] 565 kg ZE/ha/lifetime for soil with CEC of 15 meg/100 g.

The metals in sludge of most concern are zinc, copper, nickel and cadmium. This first three metals are of primary concern for their phytotoxic effect and therefore any overdosage of these metals should result in reduced production from the land. Cadmium, however, can accumulate in vegetation and reach levels toxic to animals before producing phytotoxic effects. On consumption cadmium becomes a cumulative toxin affecting the liver and kidneys.

The chemistry of solubilization of metal components in the soil is not fully understood. It can be stipulated that it is not only a question of soil pH or cation exchange capacity, but a complex interaction of soil bacteria and the plant root system. In this rhizosphere the soil solution contains organic acids, organic complexing agents and exudates from the root system in conjunction with microbial action [18].

Even the relative importance of any solubilization is unclear. As indicated by the results of VIERVEYZER [26] the quantity of metals taken up by the plants is approximately equal to the percentage soluble in water.

GARRIGAN [12] lists several guidelines used for evaluating the potential of wastewater sludge to serve as a fertilizer. One approach is to list the maximum tolerable concentration for each metal in the sludge and once one concentration is exceeded the sludge is no longer acceptable for use as fertilizer. Another more enlightened approach is to set maxima on the amount of each metal to be discharged to the land, either on an annual basis and/or a lifetime maximum. The current thinking within EPA seems to go in this direction as evidenced by the publication in the Federal Register. The suggested loadings are summarized in table 7.

Still another approach is to express the heavy metal concentration in a zinc equivalent (ZE). The ZE of a metal is the concentration of zinc needed to produce the same phytotoxic effect as that of the metal. Only the metals copper, nickel and zinc are expressed in this way as one total number. The ZE is based on findings by CHUMBLEY [5] that copper is two times and nickel eight times more phytotoxic than zinc. Therefore the ZE equals:

$$\mathrm{ZE} = (\mathrm{Zn}) + 2\,(\mathrm{Cu}) + 8\,(\mathrm{Ni}).$$

CHUMBLEY suggested a maximum load of 56 kg ZE/ha/lifetime. Other researches have refined this maximum load to the point that equations are developed including such characteristics as the cation exchange capacity (CEC) and the percentage organic material.

Most emphasis is presently given to the potential for the heavy metals to cause toxic effects on the plants and animals feeding on the plants. Another aspect that has to be taken into account, however, is the potential contamination of groundwater. VIERVEYZER in his studies reported very low percentages of the metals to be soluble in water and therefore it is not anticipated that large quantities of metals will be washed out and cause a potential threat to the groundwater. JORGENSEN [15] estimates the maximum allowable sludge load solely based on the potential contamination of groundwater. The results of this study show that the properties of the soil like pH, humus and clay content will determine the potential for washing out metals. JORGENSEN determined the metal concentration in the soil to cause a soluble metal concentration in the drain water in a concentration higher than the standards set by the WHO. In all soils investigated he determined that lead was the controlling factor and limited the sewage sludge application rate from 1,300 to 3,800 kg lead/ha/lifetime depending on the type of soil.

5. DESIGN EXAMPLE

Using data from tables 1 and 3 assume a municipal wastewater with the following metal concentrations:

copper	0.25 mg/dm^3
zinc	0.35 mg/dm^3
chromium	0.10 mg/dm^3
nickel	0.10 mg/dm^3
lead	0.20 mg/dm^3
cadmium	0.01 mg/dm^3

This composition is representative for a community with only small amounts of industrial waste discharged to the sanitary sewer.

The percentage removal for each of the metals can vary widely but based on the information presented in table 4 it seems reasonable to use the following removal percentages for this design example:

copper	60 %
zinc	60 %
chromium	60 %
nickel	20 %
lead	60 %
cadmium	60 %

With an accumulation factor of 10,000 the concentration of heavy metals in the digested sludge will be as follows (note ppm = mg/kg)

copper	1,500 ppm	(0.15 %)
zinc	2,100 ppm	(0.21 %)
chromium	600 ppm	(0.06 %)
nickel	200 ppm	(0.02 %)
lead	1,200 ppm	(0.12 %)
cadmium	60 ppm	(0.006 %)

This sludge composition seems reasonable when comparing the metal concentrations with data listed in table 5.

Applying the guidelines summarized in table 7 it is obvious that this sludge has a high metal content based on the concentration limits. This indicates that even relatively normal wastewater can contain metal concentrations that will limit the agricultural usage. In this case the maximum allowable application rates for each metal should be calculated and the limiting load will determine the land area required.

Table 8

Results by applying each of the guidelines summarized in table 8 to the sludge for the design example

Wyniki zastosowania norm (zsumowanych w tabeli 8) do osadu dla celów projektowych

A. **EPA**

Assume a soil exchange capacity of 5–15 meq/100 g

Cadmium/Zinc ratio is 0.028 which excludes the use for this sludge on an acid soil.

The total amount of sludge that can be dumped on the land based on each of the metal concentrations is:

Lead	850,000 kg/ha
Zinc	240,000 kg/ha
Copper	170,000 kg/ha
Nickel	510,000 kg/ha
Cadmium	170,000 kg/ha

The load limiting metals are cadmium and copper and the total amount of sludge that can be dumped is 170,000 kg/ha.

B. **State of Pennsylvania**

Based on maximum loading rates the sludge application rate can be:

Cadmium	18,800 kg/ha/yr
Copper	15,000 kg/ha/yr
Chromium	37,500 kg/ha/yr
Lead	18,800 kg/ha/yr
Nickel	22,500 kg/ha/yr
Zinc	21,500 kg/ha/yr

The limiting metal is copper and results in a permissible annual sludge load of 15,000 kg/ha/yr The restrictions of 3.4 kg/ha for cadmium limits the useful life of the site to about 4 years.

C. **Sweden**

Based on maximum loading rate the sludge application rate can be:

Zinc	1,450/ha/yr
Copper	950 kg/ha/yr
Lead	250 kg/ha/yr
Chromium	335 kg/ha/yr
Nickel	500 kg/ha/yr
Cadmium	245 kg/ha/yr

The limiting metal is cadmium and results in a permissible annual sludge load of 245 kg/ha/yr. With a useful life of 100 years the allowable lifetime load becomes 24,500 kg/ha.

D. **The Netherlands**

Based on maximum loading rate for cropland the sludge application rate can be:

Zinc	1,930 kg/ha/yr
Copper	675 kg/ha/yr
Nickel	505 kg/ha/yr
Cadmium	340 kg/ha/yr

The limiting metal is cadmium and results in a permissible annual sludge load of 340 kg/ha/yr. With a useful life of 100 years the allowable lifetime load becomes 34,000 kg/ha.

E. Guidelines based on maximum cadmium loadings

Applying the different guidelines for cadmium results in the following:

EPA:	allowable sludge load 17,000 to 34,000 kg/ha/yr. Lifetime limit (See A) of 170,000 kg/ha.
England:	allowable sludge load 2,800 kg/ha/yr for 30 years. Lifetime load of 84,000 kg/ha/yr.
Scandinavia:	allowable sludge load of 245 to 490 kg/ha/yr.
Keeney:	allowable sludge load of 37,500 kg/ha/yr for not more than 10 years. Lifetime load of 375,000 kg/ha/yr.
Ill. EPA:	Allowable sludge load of 5,650 kg/ha/yr for not more than 20 years. Lifetime load of 113,000 kg/ha.

F. Guidelines based on zinc equivalent

ZE $= 2100+2\times1500+8\times200 =$ 6,700 ppm (0.67%). Lifetime load according to Chumbley is 83,000 kg/ha.

G. Groundwater protection

Maximum lead load 1,300 to 3,850 kg/ha/lifetime. This limits sludge load to 1,080 to 3,200,000 kg/ha in a lifetime.

The results of these calculations are shown in table 8. Comparing the lifetime load of this sludge based on the different guidelines gives:

EPA [9]	170,000 kg/ha
State of Pennsylvania	60,000 kg/ha
Sweden [25]	24,000 kg/ha
The Netherlands [25]	34,000 kg/ha
England [25]	84,000 kg/ha
Keeney [16]	375,000 kg/ha
Illinois EPA [14]	113,000 kg/ha
Chumbley (Zinc Equivalent) [5]	83,000 kg/ha
Jorgensen (groundwater protection)	1,083,000 to 3,200,000 kg/ha

In almost all cases cadmium was the limiting metal. In EPA's case copper was limiting to the same extent as cadmium. The zinc equivalent also resulted in a lifetime load very similar to that for cadmium. Using Jorgensen's results it is apparent that groundwater contamination does not have to be a concern as long as the quidelines for protection of the crops and animals are adhered to.

In general it seems that the European countries are more conservative than the U.S. It is not certain whether this is based on experimental results or that the general attitude is more conservative. The lifetime loads reflect this attitude only partly. The U.S. approach is strongly aimed at limiting the lifetime load without being too conservative on the allowable annual loadings. In Europe, however, the trend is to issue guidelines for very conservative annual loadings but tolerate the practice for a long time.

In addition to evaluating the allowable loads based on heavy metals, the design engineer will also be required to determine the allowable load based on the nitrogen concentration. This load will depend on the crops. Typical values for the allowable load based on nitrogen content are in the range between 4,500 and 22,500 kg dry material/ha/year.

6. CONCLUSIONS

The data presented in this paper lead to the following conclusions:

1. Municipal wastewater will contain significant concentrations of heavy metals even when there are no industrial discharges.

2. The metal removal in the influent to the treatment plant can vary widely depending on a large number of factors. Typically all metals are removed for about 50–75% except nickel which is only removed for 15–30%.

3. The metals retained in the treatment plant accumulate in the digested sludge. A reasonable number for the accumulation factor is 10,000, what means that if the difference in influent and effluent concentration is 0.5 mg/dm^3, the concentration of that metal in the digested sludge will be about 5,000 ppm.

4. Guidelines proposed for limiting the heavy metal load to land used for agriculture vary widely. European countries seem to be more conservative in their approach. Especially the allowable annual loadings is much lower in Europe than in the U.S. The maximum lifetime load to the land for the different metals does not differ that much.

5. For the wastewater used in the design example in this paper, which had a more or less typical metal composition, the limiting lifetime load was based on cadmium.

6. When the guidelines for protection of the crops and animals are used, groundwater contamination due to leaching of metals is very unlikely.

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ZANIECZYSZCZENIE OSADÓW ORGANICZNYCH METALAMI CIĘŻKIMI

Stwierdzono, że metale ciężkie są usuwane w biologicznej oczyszczalni ścieków w stopniu 50–75% prócz niklu, który jest usuwany w 15–30%. Osady powstające w oczyszczalni charakteryzuje współczynnik akumulacji 10,000, tzn., że przy stężeniu 0,5 mg/dm^3 w ściekach — w osadzie stwierdza się 5000 cz. m. na mln (mg/kg). W pracy omówiono szczegółowo obowiązujące w różnych krajach normy dopuszczalnej rocznej dawki metalu w osadach, które są wykorzystywane w rolnictwie i stwierdzono, że w Europie są one niższe niż w USA. Całkowite dawki (t/ha·cały okres życia) omówiono na przykładzie opartym na dopuszczalnym stężeniu kadmu. Stwierdzono, że przy stosowaniu się do zalecanych norm dla upraw, wymywanie metali do wód gruntowych jest mało prawdopodobne.

SCHWERMETALLE IN ORGANISCHEN ABWASSERSCHLÄMMEN

Der Beseitigungsgrad von Schwermetallen beträgt im Belebungsverfahren rund 50–75%; der Nickel wird jedoch nur zu 15–30% beseitigt. Die Metalle werden vom Belebtschlamm aufgenommen, wobei der Anreicherungsgrad bei etwa 10000 liegt. Das bedeutet, daß bei einem Schwermetallgehalt im Abwasser von nur 0,5 mg/dm^3, im Schlamm mit einer Konzentration von etwa 5000 mg/kg TS zu rechnen ist.

Im vorliegenden Bericht werden die in vielen Ländern bestehenden, diverse Richtlinien und Normbedingungen für eine landwirtschaftliche Schlammverwertung besprochen. Es handelt sich im engeren Sinne um höchst zulässige Mengen pro Jahr bei Schlämmen mit Schwermetallgehalten. Maximale Jahresmengen sind in Europa niedriger als in den Vereinigten Staaten von Amerika. Als Berechnungsbeispiel dienten die Summenmengen (Mg/ha · Anwendungszeit) von Kadmium, umgerechnet auf die höchst zulässigen Konzentrationen. Werden die festgelegten Richtlinien streng befolgt, ist eine Ausspülung der Metalle in den Boden und in die Grundgewässer kaum zu befürchten.

ЗАГРЯЗНЕНИЕ ОРГАНИЧЕСКИХ ОТЛОЖЕНИЙ ТЯЖЁЛЫМИ МЕТАЛЛАМИ

Выявлено, что тяжёлые металлы удаляются на станции биологической очистки сточных вод в степени 50–75%, кроме никеля, который удаляется в 15–30%. Отложения возникающие на станции очистки сточных вод характеризует коэффициент аккумуляции 10 000, т.е. при концентрации 0,5 мг/дм^3 в сточных водах – в отложениях обнаруживается 5000 czm на mln (мг/кг).

В работе подробно обсуждены обязательные в различных странах нормы, определяющие допустимую годовую дозу металла в отложениях, используемые в сельском хозяйстве и выявлено, что в Европе они ниже, чем в США, хотя суммарные дозы (t/га · весь период жизни) обсуждены только на примере, основанном на допустимой концентрации кадмия. Выявлено, что при соблюдении рекомендуемых норм для культуры, вымывание металлов в грунтовые воды является мало вероятным.