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Evaluation of the Pollution Level of Surface and Waste Water

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ABSTRACT

The household and industrial wastes that have been accumulated during the last 40–50 years organized and spontaneous landfills (garbage dumps) pollution of the natural water bodies near locations. As results of precipitation and solar irradiation, the drainage of water formation occurs; such waters are polluted with harmful and toxic ingredients. The known indices of pollution of industrial and surface waters as well as the technique for determining the class of danger posed by solid household wastes were analyzed. The application of this technique to liquid wastes is suggested, since the change of aggregate state must not restrict its application; on the contrary, a new useful unexpected result can emerge with this. A rather simple dimensionless index of toxicity was chosen on the basis of the following examples: composition of the drainage waters of a specific landfill, content of harmful ingredients in them, excess ratio of their maximum permissible concentration. Such an index takes into account the maximum permissible concentration of the harmful substance in the ground, as well as the fraction of the harmful ingredients in the total mass of the liquid waste. Using the dimensionless index of toxicity, the bar charts were drawn, from which the sequence of removal of harmful components from the liquid mixture can be determined, starting with the component with the least value of dimensionless index of toxicity which characterizes the most dangerous component.

Keywords: industrial waste, surface water, industrial wastewater, drainage water, toxicity index, the procedure for disposal of harmful ingredients.

INTRODUCTION

The factors are called anthropogenic if they are related with human activity in their origins. Just by this, they are drastically distinguished from the natural factors, which had emerged before the humans appeared, but still exist and act. The main problem of modern anthropogenic influence consists in the discrepancy between the needs of mankind with almost unlimited scientific and technological possibilities of influence upon nature and the limited possibilities of the nature itself. Because of this, the problem of environmental protection against the disastrous influence of the human upon the nature arises. One of the most dangerous kinds of the harmful human influence upon nature is the pollution of the Earth, especially that of water bodies, atmosphere, and soil (with wastes) (Karpinski et al. 2018, Kvaternyuk et al. 2017, Pohrebennyk et al. 2017).

Nowadays, the life activity of a civilized society is connected with the formation and accumulation of great amounts of household and industrial wastes, which in some countries, because of the absence of salvaging capacities, accumulate in landfills he majority of landfills have already exceeded their design capacities (Pohrebennyk and Petryk 2017, Mitryasova et al. 2016). Besides, some of the aforesaid landfills emerged spontaneously, they lack design plans and specifications, sometimes the necessary conditions of hydroisolation of bottom were not met in the course of their construction.

The investigations that are carried out by European Agency for Environmental Protection confirm the fact that the improvement of the waste management systems which is distinct from landfilling, as well as the use of improved technologies of waste processing, can reduce the harmful influence on the environment. Fig. 1 shows a simulated emission of hot-house gases obtained by means of different methods of handling the wastes in countries of EU (EEA Report 2011).

The stagnation of wastes for many years on local territories under the influence of local factors (precipitation, solar irradiation, and others) leads to the formation of superficial and subterranean wastewaters, which uncontrollably pollute grounds and water bodies.

The investigations on the handling the wastes in Ukraine indicate that only 7–8% of them are subjected to processing: more than 90% of wastes are placed in landfills. With this, more than 50% of wastes were incinerated without obtaining useful energy.

The filtrate (filtered liquor) is the most dangerous factor of the landfills influence upon the environment components. It is a liquid form of wastes, i.e. a stream of polluted waters from the bulk of wasters beyond the boundaries of the landfill territory. Its formation contributes to the direct contact of wastes with precipitation. The peculiarity of the danger of such a filtrate consists in the fact that such liquid products of decay contain heavy metals, mineral salts, colours, surface–active substances, oil products, which under the absence of appropriate engineering structures infiltrate into the surface and ground waters and can be a source of environmental pollution for many years, even under the condition of modern engineering design of landfill equipment. During their drying, the products of non-complete decay form such a dust that is rich in pollutants and microorganisms. As result, intensive pollution of grounds, air, surface and ground waters occurs; which, in its turn, kills flora and fauna. It is worth noticing that such objects as landfills are considered as a carrier of infectious diseases. Insects, rats, birds, stray dogs and cats are carriers of pathogeneous microorganisms.

The filtrate is a mixture of organic remains which emerge due to the rotting of garbage and chemical substances; the most dangerous of them are heavy metal salts. As to their cancerogeneous content, the filtrate can be considered as equivalent to poisonous herbicides, because it is a mixed collection of harmful chemical elements (the sources of which are mercury lamps, plastic kitchen utensils with remains of lubricants, pesticides, its.) infiltrate into them. An important index of pollution of waters is their chemical oxygen demand (COD) and biological oxygen demand of (BOD); the pollution index is the amount of oxygen required in the process of chemical and biological oxidation (over a period of time) of organic substances contained by the polluted water.

Conventionally, the filtrates which flow out of the body of a landfill are classified into «primary», characteristic of the initial (acidic) stage, and «secondary», which form during the period of stabilization of processes of wastes biodegradation and contain relatively low amounts of concentrated pollutants. The penetration of filtrate into aquifers pollutes underground waters (Turkadze et al. 2006). As a rule, the protection of grounds and ground waters against pollution is carried out by means of constructing a special filtration-proof screen along the whole bottom and

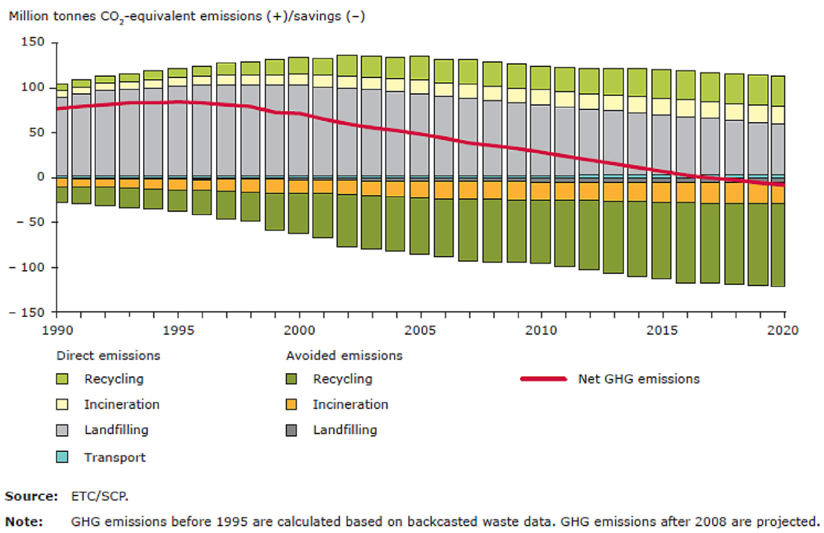

Fig. 1. Forecast of greenhouse gases emission from wastes in the EU according to the data in (EEA Report 2011)

along the perimeter of the landfill, construction of a system of trapping, removal, and purification of filtrate, as well as construction of a system of inspection holes for control of quality of ground waters. The surface waters can be polluted either by direct inflow of filtrate into water bodies (maximal harmful effect is observed then), either by the underground waters flowing into them, polluted by the filtrate, which is especially dangerous in low season.

The quality monitoring of ground waters with the aim to prevent emergency situations in landfill areas (Canada as example) is investigated in (Zaltsberg 2009). The protection of surface waters against pollution by drain waters and by the waters from melted snow that flow out of the territories of forested landfills is carried out by means of purification of surface runoff and by means of surface water diversion (Pohrebennyk et al. 2018, Styskal et al. 2016). In Table 1, the data concerning the content of filtrate of different landfills in such countries as the USA, Netherlands, Germany, Denmark, Russia, and Ukraine are presented in (Pohrebennyk et al. 2016).

In (Gronow et al. 2005, Slack et al. 2007), the composition of filtrate and ways of its migration into the ground waters are described. The possibility of forecasting changes of the chemical and physical properties of a filtrate is shown. The methods of quality control of natural waters in landfill areas of industrial waters were investigated in the Institute of Technology of Chinese Academy of Sciences (Aizhong Ding et al. 2001). In the works (Degtyar and Galkina 2019, Gaydin et al. 2013, Pohrebennyk et al. 2016), the quality of wastewater purification and recommendations concerning the purification and reclamation of the drainage water from a landfill as well as household wastes deposition were estimated.

In the Post-Soviet countries, perfect and inexpensive technologies of wastewaters (superficial waters and drainage industrial waters) are lacking. The development and spread of such technologies were sometimes hampered because of the lack of a simple and universal technique of complex pollution degree estimation, i.e. a technique which could choose an optimal sequence of main pollutants removal from wastewaters. Such an optimization of the removal sequence can ensure not only the achievement of permissible degree of pollution under the condition of reducing the number of technological purification processes, it also shows components concerning the development and improvement of the reclamation should be given attention.

The aim of the work was to develop technique involving complex estimation of the pollution degree of surface, industrial, and drainage sewage waters, selection of an index that enables to detect the most dangerous component and to determine the removal sequence of harmful components from a polluted mixture.

The existing techniques

In the known techniques for complex estimation of the degree wastewater pollution, different indices are used, they are based (Kolisnyk and Yurasov 2009, Romanenko et al. 1988, Vasenko et al. 2015, Yurasov et al. 2012) on the maximal permissible concentration (MPC) of polluting components in the medium the quality of which is to be estimated, on the multiplicity of its exceeding

Table 1. Content of filtrate of different landfills

Filtrate producing landfills	Concentration of pollutants, kg/dm³						
	Chlorides	Sulfates	Inorganic Nitrogen	Sodium	COD, mg/dm³	BOD, mg/dm³	pH
USA	96–2350	84–730	0.22–480	85–1700	100–51000	21700–30300	4–8.5
USA (primary filtrate)	2103	No data	340–576	900–2500	11600–110505	7250–8000	6.9 –7.1
USA (secondary filtrate)	320–747	No data	34–47	380–440	96–124	55–63	7.1–7.2
Netherland	743–7122	No data	438–2250	2988–333	No data	No data	No data
Germany	36–125300	18–14968	1–2892		50–35000	41–15000	5.9–11.6
Denmark (primary filtrate)	2000	500	1000	1500	21000	15000	6–7
Denmark (secondary filtrate)	2000	20	1000	1500	2000	200	7–8
Russian	381–2900	150–480	20–720		150–700	1500–4800	6.6–7.7
Ukraine	8875	1450–1500	6300		700–1300	520–800	7.7–9.1

and on the fraction (in terms of mass) of the polluting ingredient in the mixture. The simple, modified, and complex indices of water pollution (IPW, MIPW, CIPW), the coefficient of pollution (χ), the complex index of ecological state (CIES), and the generalized ecological index (I_E) belong to the set of such indices.

On the basis of the value of the actual concentration of a harmful substance or based on the multiplicity of exceeding of its MPC, the concentration is classified into its classes of danger, and the integral evaluation of the degree of pollution of a water medium is evaluated according to the known relationships (Sagdeeva et al. 2018, Shakhman and Loboda 2016, Skyba and Semchuk 2013) of the complex coefficients of pollution, with taking into account the MPC, the multiplicity of its exceeding, and the mass fraction of polluting ingredients.

They are classified on the basis of the calculated complex indices; however, in the course of an attempt to use the afore-mentioned techniques for developing a strategy of removing harmful ingredients with taking into account the material expenses, a series of shortcomings were detected. These shortcomings consist in the impossibility of unambiguous detection of those dangerous ingredients which must be removed from the polluted mixture first of all, achieving the ultimate results rather soon and with minimal expenses.

This, in our opinion, is connected with traditional approaches, which take into account only MPC of harmful in gradients in a water medium. With this, the authors of such techniques do not take into account the fact that the purified mixture which is discharged into water bodies and infiltrates into grounds (and its vapors infiltrate into atmosphere) can be also polluted.

Nowadays, State Sanitary Rules and Regulations [21] «Hygienic requirements for handling the industrial wastes and determination of their class of danger for public health» is the only officially approved in Ukraine technique of determination of the class of danger of wastes. This normative document contains some norms that do not meet the requirements of Ukrainian the legislation which is now in force and do not meet the principles of the state regulatory politics; therefore, according to the resolution No. 33 issued 15.07.2014 by the Ukrainian State Service for Issues of Regulatory Politics under the Ukrainian Ministry of Health Protection was asked to find the standards [21] unacceptable and invalid and to eliminate the violations of the principles of state regulatory politics within two-month term from the day of approval of such a decision. However, no change has been made in this document and no new rule of determining the class of danger of wastes has been developed by the Ministry of Health Protection of Ukrainian; and in practice the specialists have to use the invalid normative document, because there is no alternative.

The technique that is described in the aforementioned normative document is good for solid industrial and household wastes. However, if its approaches are used for liquid wastes, we will be able to obtain rather interesting results, since the change in the aggregate state of a substance must not essentially lessen the area of application of the aforementioned technique. In the case of extending the number objects for which the rules of [21] is valid, it is possible to obtain a new unexpectable useful result.

The second circumstance that confirms the expedience of connecting the technique for estimating the complex index of wastewaters pollution with the class of their danger, involves adaptation of Tax Code of Ukraine. According to it, the economic entity regularly pays such taxes to budget that are proportional to the amount of the emissions and to the class of danger of the complex (including liquid) wastes. The universal technique of evaluation of the index of pollution will contribute to optimization of payments and to the reduction of expenses for seeking the technologies of reclaiming harmful and dangerous ingredients of liquid wastes.

For verification of the aforesaid assumptions, the author chose a filtrate or so-called drainage waters from a landfill (located near one of the regional centers of Western Ukraine, in particular near Lviv) as the fluid of the model. Different wastes that have been for a long time accumulated there contain harmful chemical substances, compounds, and microorganisms. The penetration of non-treated or purely treated drainage waters in to underground levels can lead to the propagation (widespread) of harmful substances and threaten the environment; it is not only for water bodies, but for atmospheric air and grounds as well. However, in the aforementioned techniques, such a complex approach to polluted liquid wastes, including drainage waters, is lacking.

MATERIALS AND METHODS

The essence of determining the class of danger characterizing a compound waste (in our case it is a filtrate) consists in determining the index of toxicity for an individual chemical ingredient contained by the waste; the technique is described in DSanPiN 2.2.7.029–99, the class of danger is determined according to the following formula:

$$K_i = \frac{\lg(LD_{50})i}{(S + 0,1F + C_w)i} \quad (1)$$

where LD_{50} is the average lethal dose of the chemical ingredient following its ingestion,
S is the coefficient that characterizes the solubility of the chemical ingredient in water, F is the coefficient of volatility of the chemical ingredient,
C_w is the amount of the ingredient in the total mass of the waste or its fraction *t/t;*
i is the ordinal number of the ingredient.

After calculating the toxicity indices of all waste components, no more than three but less than two main (decisive) components which have least indices K_i of toxicity were chosen; thus, the condition $K_1<K_2<K_3$ must be satisfied; besides, the relationship $2 + K_1 >K_3$ must be satisfied as well; then the total index of toxicity is to be determined according to the following formula:

$$K_\sigma = \frac{1}{2} \cdot \sum_{i=1}^{n} K_i, n \le 3. \quad (2)$$

The determination of the degree of toxicity is present in Table 2.

However, in this document, the information concerning the concrete values of average lethal dose of LD_{50} is lacking. There is no such information in other accessible sources of information either.

In such cases, the aforementioned technique recommends to use values of LD_{50} witch are tentatively determined on the basis of the class of danger indices characterizing the ingredients in the air of the working zone. Such values are presented in Table 3.

However, for some ingredients of drainage waters or filtrates from landfills of solid household wastes, there are no developed and introduced schemes of reclamation, rendering them harmless or processing. The bulk mass of drainage waters is to be removed after their partial purification by means of discharging them into natural water bodies. In such a situation, direct contact of non-completely purified liquid wastes with an object of environment will take place. For simplification of calculations in the course of determining the class of danger of liquid wastes, the suggested technique recommends using maximal permissible concentrations (MPC) in ground, and the index of toxicity for an individual ingredient should be determined according to the formula:

$$K_i = \frac{MPC_i}{(S + 0,1F + C_w)i}. \quad (3)$$

The coefficient S of solubility of the chemical ingredient in water is determined in the following way. With a help of a reference-book, we find the solubility of the chemical ingredient in water in terms of grams per 100 g of water at a temperature no greater than 25 °C. This value is to be divided by 100, and thus the dimensionless coefficient, which in most cases is in the interval from 0 to 1, is obtained.

The coefficient F of volatility is the second addend in the denominator of the expression (1), as well as of the expression (3). It is obtained with a help of the corresponding reference-books by which the pressure of saturated vapors in mm of mercury of ingredients of the waste at a temperature of 25 °C can be determined, the ingredients being such that their boiling points are no greater than 80 °C at a pressure of 760 mm of mercury;

Table 2. Classification of dangerous wastes with respect to LD_{50}

Value of Kσ (in terms of LD_{50})	Class of danger	Degree of toxicity
Less than 1.3	I	Extremally dangerous
1.3–3.3	II	Highly dangerous
3.4–10	III	Moderately dangerous
More than 10	IV	Weakly dangerous

Table 3. Auxiliary table for determination of class of danger according to LD_{50}

Class of danger in air of working zone	Equivalent LD_{50}	Lg (LD_{50})
I	15	1.176
II	150	2.176
III	5000	3.699
IV	>5000	3.778

the obtained value is to be divided by 760 for obtaining the dimensionless value of *F,* which is in the interval from 0 to 1.

It is also worth noting that in the case of absence (for some ingredients) of one or two (out of the total number three) characteristics which are in the denominator of the expression (3), the digit 0 should be written instead of the specific value of the quantity.

The attempt to find in the known reference-books the aforementioned values for the given ingredients of pollutants of wastewaters from landfills containing solid handhold wastes, will not lead to successful results. This is accounted for by, first of all, different aggregate states, i.e. solid state and liquid state.

$$K_i = MPC_i/C_w. \quad (4)$$

RESULTS AND DISCUSSIONS

With drainage waters, many inorganic substances, including underground waters, can infiltrate into the environment. According to approximate estimations and calculations, from 300 t of solid household wastes under the actions of natural factors and for a rather durative interval of time, about 1.5 t of sodium and potassium, 1 t of calcium and 1 t of magnesium, 1 t of chlorides, 4 t of acid carbonates, 0.2 t of sulfates is absorbed into ground or infiltrates into drainage waters.

The marginal (maximal permissible) concentrations of polluting components which most frequently occur in the drainage waters from landfills, the ratio of their excess, and logarithm of such an excess are presented in Table 4.

In the last column of table, there is no information concerning the logarithm of the ratio of excess of two complex indices of drainage waters pollution, namely, BOD_5 and COD, which characterize the integral degree of pollution of sewage waters. However, such an estimation can be obtained in experimental way, and the aforementioned information cannot be further used for choice of technologies of purification. On the basis of the data of Table 4, the bar chart of excess of content of harmful ingredients has been drawn; it is shown in Figure 2.

The indices K_i of toxicity of characterizing dangerous filtrate ingredients that were calculated with the use of characteristics which are in the aforementioned tables according to the formula (4), are presented in Table 5. Besides, the last column of the table presents the dimensionless index of toxicity; this can be easily achieved, because the dimension of marginal (maximal permissible) concentration of harmful ingredients in ground is *mg/kg*, and the dimension of the fraction of a harmful ingredient is *t/t,* i.e. the units of measurement are similar.

In Figure 3, the bar chart of the calculated indices corresponding to the first eight harmful ingredients of drainage waters from a landfill of household and industrial wastes is presented, their indices of toxicity K_d do not exceed 1.2. In order to obtain these values, it is necessary to divide the corresponding values from the column 5 of Table 4 by 10^6 *t/t.*

Table 4. MPC of polluting components, ratio of excess ant its logarithm

Ordinal number	Ingredient	MPC (mg/l, g/m^3)	Excess ratio	Decimal logarithm of excess ratio
1	Dry precipitation	1000	18	1.246
2	Ions of magnesium	40	5	0.69
3	Chlorides	350	11	1.033
4	Phosphates	3.5	120	2.079
5	Ammonium nitrogen	2	360	2.556
6	Nitrates	45	2.5	0.393
7	Oil products	0.3	140	2.149
8	Compounds of iron	0.3	4	0.58
9	Compounds of lead	0.03	3	0.477
10	Compounds of nickel	0.1	1.5	0.17
11	Compounds of chromium	0.05	10	1
12	Compounds of cadmium	0.001	27	1.43
13	BOD_5	20	320	
14	COD	80	290	

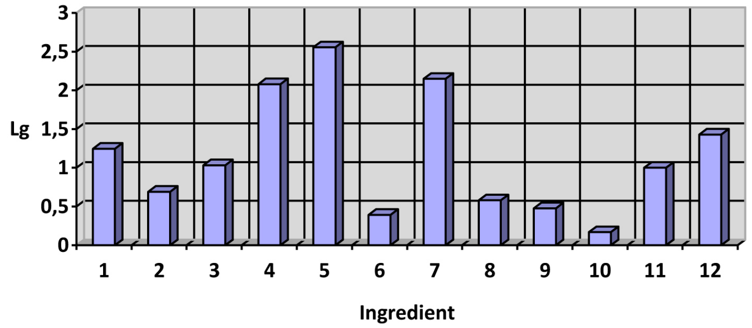

Fig. 2. Values of *Lg* of excesses ratio of actual concentration of harmful ingredients according Table 3

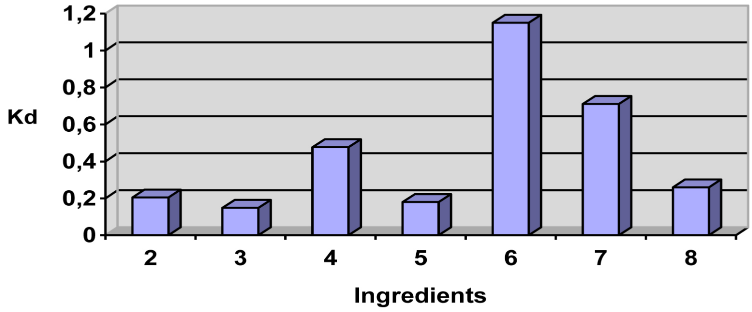

Fig. 3. Bar chart of calculated toxicity indices of ingredients 2–8

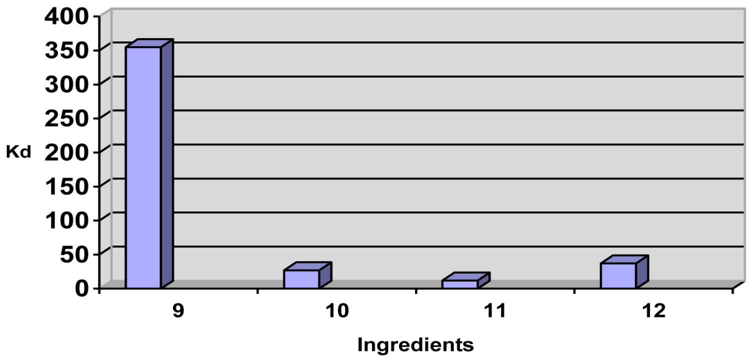

Fig. 4. Bar chart of the calculated toxicity indices of ingredients 9–12

Table 5. Reduced table of calculation of indices of toxicity of filtrate ingredients

Ordinal number	Ingredient	MPC in ground, (mg/kg)	C_w,т/т	Index of toxicity, K_i	Dimensionless index of toxicity, K_d
1	Dry precipitation		$1.76 \cdot 10^{-2}$		
2	Compounds of magnesium	40	$1.96 \cdot 10^{-4}$	$2.04 \cdot 10^{5}$	0.204
3	Chlorides	560	$3.78 \cdot 10^{-3}$	$1.48 \cdot 10^{5}$	0.148
4	Phosphates	200	$4.2 \cdot 10^{-4}$	$4.76 \cdot 10^{5}$	0.476
5	Ammonium nitrogen	130	$7.2 \cdot 10^{-4}$	$1.8 \cdot 10^{5}$	0.18
6	Nitrates	130	$1.1 \cdot 10^{-4}$	$1.18 \cdot 10^{6}$	1.18
7	Products of oil	0.3	$4.23 \cdot 10^{-5}$	$0.71 \cdot 10^{6}$	0.71
8	Compounds of iron	0.3	$1.14 \cdot 10^{-6}$	$0.26 \cdot 10^{6}$	0.26
9	Compounds of lead	32	$9 \cdot 10^{-7}$	$3.6 \cdot 10^{8}$	355
10	Compounds of nickel	4	$1.47 \cdot 10^{-7}$	$2.7 \cdot 10^{7}$	27
11	Compounds chromium	6	$4.9 \cdot 10^{-7}$	$1.2 \cdot 10^{7}$	12.2
12	Compounds of cadmium	1	$2.7 \cdot 10^{-8}$	$3.7 \cdot 10^{7}$	37

The analysis of the bar chart from Figure 3 shows that it is necessary to remove the harmful ingredients in this order: 3 – chlorides (0.148); 5 – ammonium nitrogen (0.18); 2 – compounds of magnesium (0.204); 8 – compounds of iron (0.26); 4 – phosphates (0.476); 7 – products of oil (0.71); 6 – nitrates (1.18).

In Figure 4, the same kind of bar chart of toxicity indices of harmful ingredients, the values of which are considerably higher, is presented. This indicates slight danger from them. The analysis of the data presented in the bar charts of Figure 3 showed that in the final stage, it is necessary to remove harmful ingredients in this order: 11 – compounds chromium (12.2); 10 – compounds of nickel (27); 12 – compounds of cadmium (37); 9 – compounds of lead (355).

CONCLUSIONS

Industrial wastes are essential source of environmental pollution. Rational handling of the wastes is one of the most important tasks of ecology to be fulfilled by mankind. However, the storage of wastes is the most widespread method of handling. Construction of landfills for burial of wastes gives rise to a number of problems, one of which is formation of filtrates. If an appropriate organized purification and removal of wastes is lacking, the wastes harmfully influence the environment, polluting the environment with organic and inorganic substances. Taking into account intensive increase in amounts of accumulation of wastes, the problem of handling the filtrates from landfills is extremally urgent nowadays, it calls for some effective mechanisms for its solution. It was shown that the chemical composition of the filtrates from landfills is not the same for different administrative regions, and all the more, for different countries; it also changes depending on the duration of wastes residence in the body of a landfill, and accordingly, the approaches to handling a filtrate should be different depending on its chemical composition. The chemical composition of filtrates does not meet the requirements to the composition and properties of wastewaters from industrial enterprises for safe drainage by a sewerage network, the permissible values of quality indices of wastewaters are not met either.

The indices of pollution of industrial and surface waters based on the permissible concentration of polluting components in a medium have been analyzed. Such indices are the following:simple modified, and complex indices of water pollution (IWP, MIWP, and CTWP, respectively), the coefficient (χ) of pollution, complex index of biological state (CIBS), and the generalized ecological index (I_E). An improved technique for the estimation of danger of industrial and superficial wastewaters (in particular, drainage waters from landfills) that enables us to obtain a simple expression of indices of their toxicity has been suggested. The graphic presentation of the dimensionless index of toxicity of component of polluted waters in the form of bar charts indicates the sequence of removal of the most dangerous components from a water mixture.

Further investigations should involve complex evaluation of water quality, since the use of such indices as average lethal dose of the ingredient LD_{50}, solubility S of the chemical ingredient in water, the coefficient F of volatility of the chemical ingredient, its class of danger in the air of the working zone and MPC in the ground is not sufficient for the determination of the dangerous properties of wastes. All these indices take into account the influence of wastes or of that of their ingredients only upon the human organism, their danger for other living organism and for environment being not taken into account there.

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