Строительство уникальных зданий и сооружений. ISSN 2304-6295. 8 (23). 2014. 48-66

Construction of Unique Buildings and Structures

journal homepage: www.unistroy.spb.ru

Geoecological aspects of municipal solid waste containing hazardous components treatment

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ARTICLE INFO

Analytical review

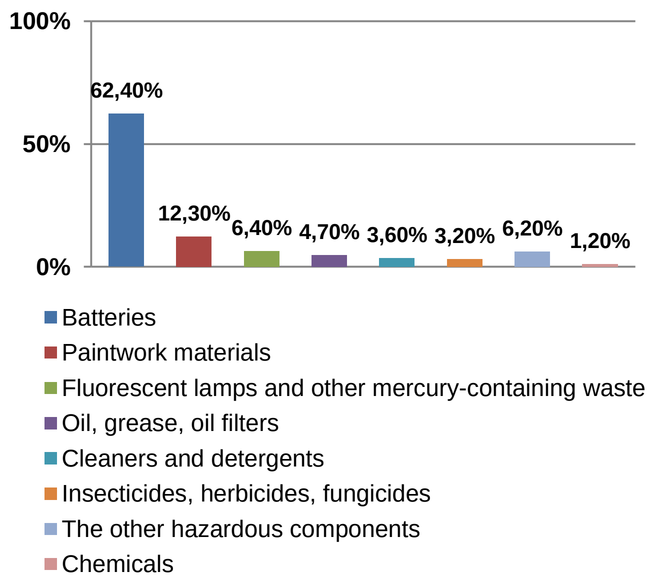
Article history

Received 29 January 2014
Accepted 2 July 2014

Key words

hazardous components of MSW,
class of waste hazard,
morphological composition,
special MSW treatment,
environment impact

ABSTRACT



While the use of various electrical and electronic devices, household chemistry some measuring devices and others in everyday life grows, and their service life is reduced, their share in the structure of municipal solid waste (MSW) continues to increase.

These devices and chemicals named household hazardous waste (HHW) contain toxic substances and may cause negative impacts on the environment in the collection and processing of mixed MSW.

The tasks of this study are to evaluate the degree of the impact of HHW, contained in the solid waste on the environment; to analyze the modern technologies of MSW treatment taking into account the presence of toxic substances; to make a review of modern technologies of separate HHW treatment and recycling. The study presents the estimation of hazard class modern MSW morphological composition (according to literature sources) by calculation method, taking into account the presence of HHW.

Analysis of publications considering the impacts of HHW in MSW on the environment in the most common methods of MSW handling is performed. An overview of technologies in HHW treatment and recycling is presented. The results of the study show that the presence of HHW in MSW may increase the hazard class of the total waste mass and thus the improvement of currently used technologies is required (burial, incineration, composting). On the other hand, the development of separate collection of HHW and the introduction of effective technologies of their treatment and recycling is an integral part of the modern system of MSW treatment.

Contents

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1. Introduction

In the last decades all over the world, the increase in the mass of hazardous household waste (HHW) in a percentage of the composition of MSWis observed. These components include: waste electrical and electronic equipment (WEEE), chemical sources of a current, measuring and lighting fixtures, household chemistry, varnish and paint materials and medicines etc. They contain toxic chemicals (toxic metals and their compounds, aggressive acids and bases, carcinogenic chlororganic compounds and other).According to U.S. researchers, already more than 20 years ago in everyday consumer products more than 27,000 toxic chemicals were detected [1]. In recent years, the share of the HHW in the morphological composition of MSW is, according to various estimates, 1-2 % in different countries and continues to grow gradually [2-7].

In most developed economies separate collection and utilization of HHWis provided by local authorities or state programs. But 100% separate collection and disposal of HHW is currently nowhere achieved [8]. According to the available scientific and analytical data [6] the risks to the environment and human health from the disposal of HHW have not been yet evaluated. Public data on this problem are still incomplete and scattered.

In Russian Federation till now no sufficient studies have been done of HHW quantities and composition. The share of HHW in MSW morphological composition can be taken similarly the European as about 1%according to the work [9].

Hazardous waste management in General and determination of the degree of their danger is regulated by normative legal acts of the Russian Federation. Currently in different Russian regions the projects on the collection and safe disposal of HHW supported with the legal and administrative level are realized [10-12]. Gradually new technologies of processing of HHW are introduced [13].Public organizations promoting and developing the network of collection of some types of HHW are evolving [14-16].

2. Literature review

The first scientific publications about the problem of HHW began to appear in international editions around since the middle of 1980-ies.For example, the article [17] reported about successful launch of a system to collect hazardous waste from households and small businesses for collection of domestic hazardous waste in Florida, USA by The Florida Department of Environmental Regulation.

The first task for the comprehensive study and solution of the problem of HHW in the composition of MSW became quantitative assessment. In 1985 a quantitative assessment of the characteristics, quantities, and impacts of non-regulated hazardous waste present in the municipal solid waste of the City of Seattle (King County, Washington) was conducted. During the study, waste was sampled and manually sorted at transfer stations to identify the types and mass percentage of non-regulated hazardous wastes. Selected samples were subjected to detailed chemical analyses. This project represented the first scientifically-structured study to characterize quantitatively the prevalence and composition of HHW in a MSW stream. As an illustration, the chemical species and quantities entering via solvents were shown [18].

In the study [19] a review of recent studies (till 1993) on the sources of hazardous compounds emitted from solid waste landfills was made. The presence of hazardous pollutants in liquid and gaseous landfill emissions is well documented; however, the source of these pollutants is not always apparent. Potential sources of such hazardous contaminants in MSW landfills are recognized as HHW. Several surveys had different estimations of quantity and characteristics of HHW ranging from 0,002 % to 0,5 % by weight. Later experimental-analytical sources provide the dispersion of the values of the content of the HHW in MSW from 0% to 5%. In 2004, still there was a significant lack of information on the number of HHW and their impact on human health and the environment [6, 10]. A separate study focused on the main dangerous components included in composition of the HHW [20-22].

Contemporary foreign studies show higher results of HHW containment in MSW: for example 3,49% [23].There are some publications of the research results of the qualitative composition of HHW [4]. But in General, in scientific publications research there is a lack of data of the composition and quantity of HHW. More publications devoted to the problem of collection of hazardous waste from households than their composition and impact on the environment [24-26].

The first Russian studies of hazardous waste in the composition of household were conducted in the mid-2000s [27, 28].

For the safe treatment and recycling of separately collected HHW the development of special technologies is required. Technologies of processing of such common components such as accumulators, batteries, mercury-containing fluorescent lamps currently are widely spread and developing efficiently [50-52 and others]. Recycling or disposal of components such as, for example, expired medicine, raises a number of difficulties, due to the considerable uncertainty of their composition and quantity [53].

3. Problem definition

The objectives of the study are:

- to assess the hazard class of MSW, taking into account the content of HHW in accordance with approved in Russia calculation methods; to identify the main geoecological aspects of MSW containing HHW treatment;
- to identify the main geoecological aspects of MSW containing HHW treatment;
- to consider the currently existing methods to reduce the content of such components in the composition of MSW in Russia and abroad;
- toidentify priority activities to reduce environmental damage from falling HHW in the environment and review contemporary technologies (including best available technologies) in HHW recycling and treatment.

4. Description of the research (Main part of the article)

Despite the relatively small share of HHW in the overall composition of MSW, this amount is enough to increase the hazard class of MSW compared with enshrined in the Federal classification catalogue of waste 4 («hazardous waste») and 5 («practically non-hazardous waste») classes for MSW [29].

Assessment of the hazard class of solid waste containing HC can be performed in accordance with approved in the Russian Federation Criteria [30].

In the earlier study [31] was shown that transition of a class of danger of an unit mass of practically non-hazardous waste (hazard class 5) to the higher classes of danger occurs when adding a certain number of the most common toxic substances contained in HHW (mercury, cadmium, lead).For example, adding less than 0,03% of mercury to 1 kg of hazardous waste is sufficient to rise the estimated hazard class from 5-th to 4, less than 0,4% - to 3.So, introduction of a relatively minor amount of toxic substances greatly increases the hazard class of a unit mass of MSW.

Problem with the estimation of hazard class MSW with modern morphological composition (calculation method) is uncertainty about the component and the chemical composition of HHW.

Due to lack of reliable systematized data about the component composition and chemical composition of HHW in the Russian Federation, as a source of data on the composition of the HHW the data of foreign studies was used [32, 33]. The average composition of the HC in Germany, that fall in the overall flow of MSW, is presented in figure 1.

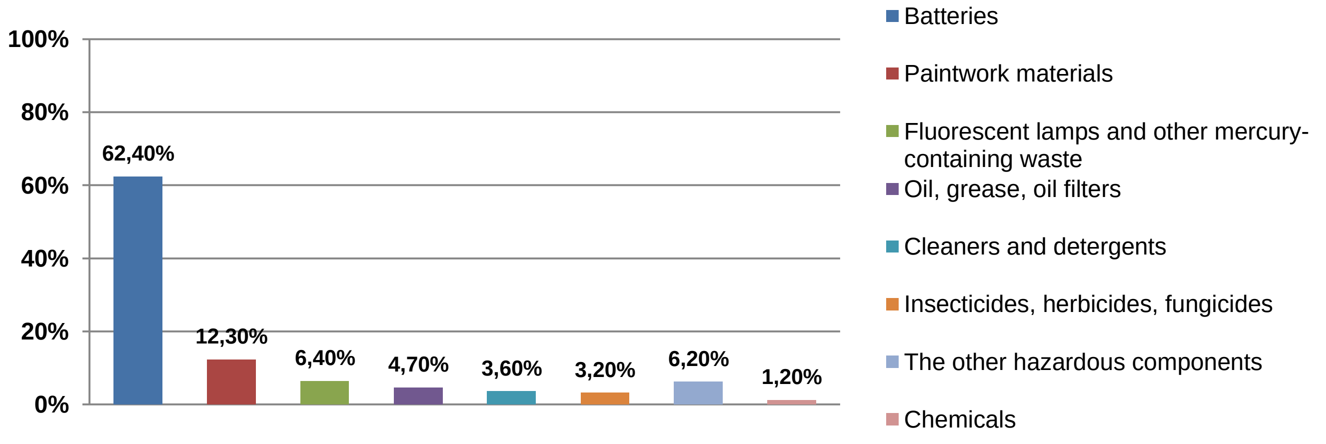

Figure 1.The average composition of the hazardous components falling into the General stream of MSW in Germany [32]

The main part of HHW (>85 % by weight) make chemical power sources (batteries), paintwork materials (coatings), mercury-containing waste and various technical oils (oil, grease, oil filters).For each of the four hazardous components types the following content of toxic substances was conditionally accepted (based on literature sources).

Table 1. The content of toxic substances in HHW (in mass %)

Componentname	Mainpollutants
Paints[34]	Lead - 1%
Batteries[35]	Zinc - 23% Magnesium - 5% Mercury - 0,0077 % Lead - 4% Cadmium - 1%
Oils, fats	to calculate taken as toluene, hazard class 3
Mercury-containing waste[33]	In lighting (lamps), in the average, 0,02 %

Hazard class of a unit mass of solid waste with a certain percentage of HHW the above composition is determined by calculation in accordance with the approved Criteria [30].

The classification of waste to a class of danger is executed by calculating the index of the degree of hazard for the environment (K) and its reference to the range corresponding to one or another class of hazard.

Indicator of the degree of danger of waste is obtained by the summation of the dangerous substances included in its chemical composition:

$$K = \sum_{i=1}^{n} K_i \quad (1)$$

K - index of the degree of hazard of waste for the environment;
K_1, K_2, ...K_i- indexes of the degree of hazard of the individual components of the waste to the environment.

The index of the degree of hazard of the individual component of the waste to the environment K_i is calculated by the formula:

$$K_i = \frac{C_i}{W_i} \quad (2)$$

C_i - the concentration of the i-thcomponent in a waste mass (mg/kg waste);

W_i - coefficient degree of danger of the i-th component of hazardous waste for the environment (mg/kg).

The coefficient W_i is calculated by formulae or taken from the table for the most common substances as permanent[30].

In accordance with Table 1, hazardous substances in the chemical composition of the HHW constitute no more than 30%. For other elements of HHW, in the framework of this calculation, has been conditionally taken coefficient W_i =18182 corresponding to the average value of the index of the degree of danger for the 4th grade.

Proceeding from the fact that HHW are averaged 1%[9] and 3,5% [23]of solid waste by weight (with the account of the composition (figure 1) , the calculation is performed for two cases for 2 cases:

1. the basic mass of MSW contains 99% practically non-hazardous (food) wastes of 5-th class of hazard;W_i =1000000;

2. the basic mass of MSW contains 99% mixture of low-hazard hazard class 4 (food waste, paper, cardboard, wood, metals, textiles, ivory, glass, leather, rubber, stones, plaster, fines), W_i =18182.

Results of calculation are presented in table 2.

Table 2. The results of calculation of a class of hazard of MSWcontaining HHW

Mass content HHW in MSW	Rate risk K hazard		Class of solid waste containing HHW	
	for 99% practically non-hazardous solid waste (5 CL, W=106)	for 99% of low-hazard MSW (4 CL, W=18182)	for 99% practically non-hazardous solid waste (5 CL, W=106)	for 99% of low-hazard MSW (4 CL, W=18182)
1%	16	69	4	4
3,5%	52	104	4	3

It should be noted that the definition of a hazard class waste by calculation is very approximate. To clarify the class of hazardous waste is used experimental method based on biotesting of aqueous extract of waste [30]. Given the significant heterogeneity of solid waste, there can be substantial variation hazardous properties of the analyzed samples, depending on the availability and types of HHW in the selected sample.

Increase of the hazard class of MSW established by the calculation and a number of studies, which reveal the MSW treatment plants influence on the environment [36-41], indicate the necessity of the application of special technologies for their processing and neutralization for the environment protection.

Because of the accumulation of toxic substances contained in HHW (heavy metals, acids and alkalis, organochlorine compounds and other), in the thick of solid waste takes place inhibition of microorganisms, providing organic degradation of dump masses. As a result, takes place inhibition of processes of biodegradation of waste and generation of biogas.

Dependence of the rate of biodegradation of organic waste and emission of biogas from the content of the HC in solid waste is the subject of a separate study, which includes laboratory and field tests and comparing the results.

At the same time, disposed at landfills and waste dumps, HHW can have direct toxic effects on the natural environment.So, if swallowed toxic substances (heavy metals, salts, acids and hazardous organic compounds) in the landfill leachate, there is pollution of surface and underground waters when it leachates beyond the body of the landfill.Due to mobility of the liquid filtrate contained toxic substances can travel considerable distances in the pore spaces in the soil. In addition to moving of toxic compounds together with a leachate, there is direct soil pollution toxicants on the location of the dump masses, which is confirmed by studies [42. 43] and significantly limits the use of the former territories of sites and landfills after closure and reclamation.

Contribution of HHW into the atmospheric air pollution at their disposal on landfills arises primarily from conflagration of dump masses, that take place regularly.Also emission of volatile toxicants (for example, mercury vapor of volatile chemical compounds) is possible during the depressurization of the tanks that contain them. Entry of heavy metals accumulated in the composition of the buried HHW, in the soil layers leads to bio accumulating in plants growing in the zone of influence of a landfill [44]. So there are secondary violation of technogenic ecosystems, established in the territory of cards of the landfill and the area of infiltration of atmospheric precipitation into the soil through the landfill masses.

Incinerators and compact installations of thermal neutralization of different types of waste, including mixed MSW, lately gain popularity in Russia despite the risk of hazardous emissions into the atmospheric air of residential areas. At combustion of mixed MSW, the most hazardous substances, given off into the air, are dioxins (and dioxin-like substances). Dioxins are formed during combustion organ chlorine compounds, in particular polyvinylchloride (PVC), which carried casing and components of such species HHW as electronic and home appliances. German researchers found that the combustion of one kilogram of PVC produces up to 50 micrograms of dioxin. This is enough for the development of tumors in 50 thousand laboratory animals [43].The heterogeneity of the mass of solid waste is an important factor hampering the passing of combustion processes in accordance with the preset parameters. In particular, incombustible metal fractions have an influence on the combustion temperature of fuel [44]. Non-observance of temperature condition and instability of the combustion process, in turn, may lead to higher concentrations of pollutants in exhaust gases and violation of purification systems. Thus, during the combustion of mixed MSW containing HHW, a higher efficiency control systems for gas purification is required.

Toxic metals that are present in HHW, after the burning of the total waste mass, become part of the ash, thereby increasing its hazard class, making it unsafe to use in building materials and by landfill disposal.

The technology of composting of MSW in Russia now is not widespread. Existing enterprises of mechanical processing of household waste, such as MPBO-1 and MPBO-2 in St. Petersburg (design capacity of 900 and 600 thousand m^3 of solid waste per year, respectively [9]), are currently technologically obsolete and do not provide a safe and efficient processing of solid waste. The designated purpose of such plants at design time (70-s and 90-s) was the processing of food and the organic fraction of MSW, obtaining compost suitable for use in the agricultural and gardening farms.

Currently, the compost, produced on special bio-drums by these enterprises, contains many impurities and, according to the study [28], is unsuitable for use, both in agricultural production and gardening sector. This compost is sent as a bedding material for isolation of filled landfill parts. Accordingly, contained in the compost heavy metals from not sufficiently sorted waste arrive at the landfill in already associated with soil substrate form. Overseas studies [46] showed that the content of heavy metals in compost obtained from MSW without preliminary sorting, exceeds existing norms for organic fertilizers: cadmium - approximately in 2 times, copper - in 1,5 times, on lead - in 2.5 times, zinc - in 2 times, on nickel - slightly (about 5%).

Furthermore, the presence of heavy metals and toxic compounds in the composition of partially sorted mass of solid waste, filed on drums bio-composting, can contribute to the inhibition of the processes of biothermal composting due to the oppression and destruction of the thermophile bacteria. Generated on MPBO so-called «tails» with unstudied morphological composition are also subsequently sent to landfills. According to the plant specialists, MPBO-2, the number of selectable useful fractions for recycling is not more than 7-10% of the total number of incoming waste (500 tons per day). Separate collection of HHW on manual pipeline during selection of recyclable materials is not provided.

In addition to the danger of contamination of the environment by hazardous substances present in the modern morphological composition of MSW, necessity for introduction of technologies for the separation HHW from the General flow of solid waste is caused by the loss of valuable material resources, possessing the properties of toxicity, that demand a significant resource and power inputs in their production.

Certain measures should be adopted for improvement of technologies for processing MSW. Development and adoption of legislative base for the extraction of HHW from MSW and to prevent their release to the environment is required [47, 48].

The main complexity of the treatment of HHW is the multicomponent nature of their composition. Consider the most common fractions of hazardous waste (according to the fig. 2) and the ways of their treatment.

Most effectively recycled chemical current sources are car batteries (accumulators) [54]. The main toxic substance in the composition of the battery is a lead. Lead in its pure form is about 18 % by weight of battery and approximately 50% - various lead compounds [55]. There are two ways of preparing car accumulators: manual processing or automatic processing. Automatic processing allows processing a larger party with a more complete selection of valuable recyclable materials. Generally, the process of recycling of car batteries is as follows. The battery is broken apart in a hammer mill; a machine that hammers the battery into pieces. The broken battery pieces are then placed into a vat, where the lead and heavy materials fall to the bottom and the plastic floats. At this point, the polypropylene pieces are scooped away and the liquids are drawn off, leaving the lead and heavy metals. Each of the materials goes into a different recycling “streams”: plastic, lead and sulfuric acid [56].

Processing of portable batteries used in household appliances, is realized much more difficult due to the complexity of their extraction from the overall composition of MSW, small sizes and differences in chemical composition.

In Russian Federation, beginning in 2013, launched the first production recycling of batteries on the basis of enterprise of Megapolisresursin Chelyabinsk. The company processes manganese-zinc (MnZn), Nickel metal hydride (NiMH), lithium ion (Li-ion), silver-zinc (AgZn) and Nickel cadmium (NiCd) with an efficiency of up to 80% (up from some foreign analogues).The company power at the moment is up to 60 tons of batteries a year[57, 58].

In Finland there is an innovative production for recycling of batteries with dry method, which allows allocate up to 90% of substances contained in them for use as raw materials. The recycling enterprise, AkkuSer Oy, has developed a chemical method for processing alkaline batteries, in response to the needs of the chemicals industry. AkkuSer has been collecting and recycling rechargeable batteries and accumulators from the EU since 2006. Of the materials recovered, Li-ion and Li-polymer are supplied as powder to OMG's chemical plant in Kokkola while NiMH is sent to Norilsk Nickel in Harjavalta. AkkuSer's method for chemical processing of alkaline batteries takes place at room temperature so it consumes a fraction of the energy required by the foundry method. Investment costs are also significantly lower than with smelter technology, which requires substantial initial spending and the recovery rate is almost twice as good as smelters can offer [59, 60].

The one of the leading battery recycling enterprise in Europe is Redux GmbH located in Dietzenbach and Bremerhaven. The enterprise offers full cycle from separate collection to recycling of batteries. The technical facilities at Redux GmbH enable to recycle zinc-carbon batteries (ZnC), alkaline-manganese batteries (AlMn), nickel-metal hydride batteries (NiMh) and construction site/warning lamp batteries [61, 62].

In the U.S. there are also large productions and processing of chemical current sources of different types.SoBattery Solutions provides cost-effective fully-managed battery-recycling kits, systems, and services to corporations, governments, municipalities, and households across the country to serve environmentally conscious individuals and businesses and satisfy compliance with government regulations since 1971. The organization provides recycling of Alkaline/Zinc Carbon/Zinc Air Batteries, Lithium Ion Batteries, Nickel-Cadmium, Nickel Metal Hydride Batteries, Lithium Batteries and Mercury Batteries [56].

In the last decade, the scientific developments in the field of technologies for the safe recycling of chemical current sources with the separation of valuable components are produced in many countries of the world [63-69].

In Russia collecting and recycling of household waste paint and varnish materials and household chemical residues, generated in the population, is not established. Some collection points of HHW take such waste, but in the future they are mostly disposed at the landfill of toxic waste [70].Coatings are complex multicomponent structure with varying degrees of toxicity. The results of the quantitative analysis by gas chromatography of organic compounds emitted from coatings show the excess of maximum permissible concentrations of certain substances in dozens of times [71-73].

In many developed countries the collection of paint and varnish waste from the population working quite effectively. For example in UK there are special Household Waste Recycling Centers that accept a long list of different paint and varnish materials [74]. In Australia, different companies organize the collection and processing of paint and varnish waste from the population, for example, [75].

In each state of Australia, water and solvent based paint is the greatest material collected by weight, ranging from 43% to 56% of waste collected. There are differences between states in the way the paint and varnish materials are treated. In Western Australia water based paints are treated by fixation and landfilling. In South Australia paint and flammable liquids are treated by distillation. The cleaned solvents are on sold, and the wastes from the process are incinerated. Water is extracted from the water based paints, and the residue is landfilled. In Victoria, Almost all liquid waste sent to Geocycle Victoria, who uses it to make fuel blends to fuel cement kilns. Waste that needs plasma arc treatment is sent interstate [76, 77].

Technologies for processing of mercury-containing waste are developing in Russia and abroad for a long time [78-79, 86-88]. The most significant part of the mercury containing wastes from organizations and residential premises are fluorescent lamps. First, recycling of mercury-containing sources, mainly concerned fluorescent lamps from industrial and non-residential premises, but in the last decade has dramatically increased the number of compact fluorescent lamps used in everyday life, which have their own peculiarities collection and processing. The main difficulty to manage such waste is the fragility of glass bulbs and tightness of which is immediate evaporation of mercury vapor [80].

Scientists estimated [81, 82] that the disposal of waste (production and consumption) is on the fifth place in the number of mercury emissions into the air after the burning of fossil fuels in thermal power plants, artisanal gold mining, non-ferrous metals manufacturing and cement production.

The most effective technology for processing of mercury lamps allow not only to reduce the hazard class of the final product processing, but also to select the maximum number of pure mercury for reuse in production.

Hydrometallurgical (liquid phase) method of demercurization is considered one of the most ecologically clean and provides almost full recovery of mercury. In accordance with this method used lamps are wet grinding in a ball mill with simultaneous washing in two stages mercury and phosphor glass and bases in a specially developed solution [83]. For decentralized processing of mercury-containing waste in recent years mobile demercurization units are used allowing to allocate raw materials suitable for secondary processing [84, 85].

Technologies of processing of technical oils in this review will not be considered, because the collection and processing of such wastes as a component of HHW is similar to waste paint and varnish materials.

A brief look at the technology of recycling of household electronic scrap (WEEE) as the most problematic fraction of hazardous waste (in Fig. 2 this fraction may be considered as “the other hazardous components”).

In Russia collecting from the population and the processing of WEEE began to develop in the framework of the special shares that are held by the networks of shops of electronic and home appliances [89]. But the number and capacity of enterprises for the processing of electronic scrap is limited: for example, in Moscow operates only one enterprise that meets the necessary requirements. When ensure processing capacity of 2.5 thousand tons of scrap per year, the need for the processing of electronic scrap for Moscow is 60 tons annually [90].

In General, recycling of WEEE that is different multi-component composition is as follows. Electronic equipment is dismantled manually sorted by types of material and dismissed from the possible hazardous components. In the further processing sorted material is a crushed, screened and divided into faction with the help of technological processing, which retrieved the steel, nonferrous metals and subjected to treatment faction [91, 92]. In addition to the processing of precious metals from waste electronic equipment, it is necessary to ensure efficient processing of polymeric materials in its structure [93-98].

5. Conclusions

Thus, the presented estimation by calculation method confirms the urgency of the problem: increasing the flow of HHW in the composition of MSW increases their hazard class, which requires the improvement of the currently used technology of its treatment (burial, incineration, composting). The negative effects of HHW in the composition of MSW, including the accumulated environmental damage [99-100] now confirmed and estimated number of scientists.

Solution of the problem of solid waste, containing a growing number of different hazardous components in the Russian Federation currently has the following key components (which are gradually being introduced in the system of waste treatment in developed countries):

1. Normative-legal regulation of allocation of hazardous components from the General MSW stream.

2. Introduction of efficient methods (best available techniques) of neutralization and recycling of hazardous components of solid waste.

3. Design and operation of enterprises for the handling of MSW, taking into account potential for incomplete recoveryof HHW from the solid waste stream.

4. Elimination of accumulated environmental damage as a result of MSW treatment without accounting for the presence of hazardous components in their composition.

When solving the problem of hazardous waste in the composition of municipal solid waste, a variety of international experience should be considered and adapted to the Russian reality.

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Геоэкологические аспекты обращения с ТБО, содержащими опасные компоненты

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Информация о статье	История	Ключевые слова
Аналитический обзор УДК 504.054	Подана в редакцию 29 января 2014 Принята 2 июля 2014	опасные компоненты ТБО, класс опасности отхода, морфологический состав, обращение с ТБО, воздействие на окружающую среду.

АННОТАЦИЯ

Из-за роста содержания опасных компонентов в составе твердых бытовых отходов (ТБО), последние приобретают более высокий класс опасности. Опасные компоненты ТБО оказывают негативное воздействие на окружающую среду при захоронении ТБО на полигонах, сжигании на специальных установках или компостировании.

В статье расчетным методом показан рост класса опасности ТБО, в зависимости от содержания в их составе опасных компонентов. Также рассмотрены основные пути воздействия опасных компонентов ТБО на окружающую среду и меры по его сокращению. Проведен краткий обзор существующих технологий обезвреживания и утилизации основных видов опасных компонентов ТБО.

Представленный анализ показывает, что наличие опасных компонентов в составе ТБО может повысить класс опасности общей массы отходов и, поэтому требуется совершенствование используемых технологий обращения с ТБО (захоронение, сжигание, компостирование). При этом развитие раздельного сбора опасных компонентов ТБО и внедрение эффективных технологий их переработки и повторного использования является неотъемлемой частью современной системы обращения с бытовыми отходами.

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