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TOXIC SUBSTANCES IN HAZARDOUS HOUSEHOLD WASTE

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ABSTRACT

Many countries have no waste separation and mixed household waste accumulated mostly in landfills could pose serious environmental risk if landfills do not fulfill the requirements. The risk becomes much higher with increasing of hazardous components quantities in household waste (having hazardous properties and containing toxic chemicals). These include batteries, fluorescent lamps, chlorine-containing plastics, aromatic compounds and many others. Some hazardous waste are toxic themselves (waste oils) and some are not dangerous but contain toxic chemicals which are able to release into the environment under specific conditions.

The purpose of this paper is the detailed study on hazardous components in household waste and the analysis of chemicals constituting these components and posing a threat to the environment and human.

The profound literature review is used for the assessment of different hazardous household waste. Also, original investigations are carried out to identify toxic chemicals in some hazardous household waste: the chemical composition and data of manufacturers of batteries, cleanings, personal care products and fluorescent lamps are analyzed.

The main hazardous components of household waste are analyzed: paints and varnishes, batteries, mercury-containing waste, waste of electrical and electronic equipment, cleaning products, medical waste, residues of pesticides and fertilizers, personal hygiene products. Hazardous substances contained in such components are considered. On the basis of detailed literature analysis and own research, it was investigated they are in a very large quantities. Among the most widespread substances are heavy metals, aromatic hydrocarbons, as well as many other carcinogenic and aggressive organic and inorganic compounds.

The analysis shows household waste consisting of large number of hazardous components (fluorescent lamps, batteries, detergent residues, etc.) containing many toxic substances, including heavy metals, aromatic hydrocarbons and many other

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aggressive, carcinogenic organic and inorganic compounds. If hazardous components are mixed with household waste, then the hazard level of household waste and the operating costs sharply increase.

Keywords: toxic substances, hazardous household waste, environment

INTRODUCTION

The proper household waste management is of high importance for every country. This is because the problems associated to household waste are both environmental and social. Many countries have no waste separation and mixed household waste accumulated mostly in landfills could pose serious environmental risk if landfills do not fulfill the requirements. The risk becomes much higher with increasing of hazardous components quantities in household waste (having hazardous properties and containing toxic chemicals). These include batteries, fluorescent lamps, chlorine-containing plastics, aromatic compounds and many others. Some hazardous waste are toxic themselves (waste oils) and some are not dangerous but contain toxic chemicals which are able to release into the environment under specific conditions. Besides, new pollutants such as 1,4-dioxane [1] may be formed in landfills. The heavy metals and halogenated hydrocarbons are known to be the main source of groundwater pollution. The quantity and diversity of such waste is constantly increasing. The share of hazardous components in household waste varies from 0.5 to 1 % in different countries (up to 5 % if taking into account waste of electrical and electronic equipment). There is more than 1.5 million tons of hazardous household waste generated per year in the USA (up to 0.5 % of total household waste mass), and from 20,000 to 400,000 tons per year in the UK (up to 1 %) [2]. An average hazardous household waste generation in the EU is 2-3 kg/year per person [3]. The amount this waste depends on many factors: the level of people’s income, living conditions, climate, etc. Although the amount of hazardous household waste is considerably smaller compared to other household waste components, their variety and strong impact cause a significant environmental risk when emitted to the environment.

The consequence of hazardous components presence in household waste is the emitting of many harmful substances into the environment along with the landfill leachate. For example, there are more than 50 pollutants in the leachate: heavy metals and many dangerous organic contaminants (phthalates, benzene and its derivatives, polychlorinated biphenyls, and many others). Besides, the landfills are significant long-term sources of these substances for many years.

Most researchers have analyzed the hazardous components content in certain waste types. The task of this study is wider: consider all household waste based on literary review and own research. Therefore, the purpose of this work is: a) to study the hazardous components in household waste; b) to analyze the chemicals contained in hazardous household waste and posing a threat to the environment and humans.

MATERIALS AND METHODS

The profound literature review was performed for the assessment of different hazardous household waste. Also, original investigations are carried out to identify toxic chemicals in some hazardous household waste: the chemical composition and data of manufacturers of batteries, cleanings, personal care products and fluorescent lamps are analyzed.

RESULTS AND DISCUSSIONS

Below is a detailed analysis of hazardous components in the household waste.

Paints, adhesives, solvents

Paints are among the main sources of lead in the households. Pb usage has decreased in the paints due to strict environmental standards (in some countries, lead is banned to use in paints). Today, many soils contain Pb accumulated during the period when paints contained up to 10 % lead [4, 5]. Pb can appear in the household waste not only along with the residual paints but also along with the dust formed during the walls treatment (grinding). According to the study [2], house paints in the UK in the 1990's contained only 0.0135 % Pb, while in the 19 century – 14.1 %. Besides, the danger of Pb usage in paints was proven by the authors [4], which revealed a two-fold excess of Pb content in soils near painted houses compared to unpainted ones. Moreover, Pb concentration in some soils was more than 6000 mg/kg that is significantly above the limit (in different countries: 400 mg/kg, 0.5 %, 5,000 ppm). Modern paints contain less lead. Although the authors [5] have measured Pb concentration of up to 1,500 ppm in paints used in new buildings, and over 50,000 ppm in old buildings. Another study [4] has shown lead average concentration in household paints 35,000 mg/kg. The current lead content of household paints is usually less than 90 ppm, although some paints may contain up to 10,000 ppm lead. In the past, mercury was widely used in paints (average concentration 15 mg/kg [4]).

Today, mercury content in paints is strictly limited in many countries and therefore is very low. Paint pigments contain oxides and salts of metals [2]: lead carbonate, zinc sulfide, zinc chromate, lead chromate and sulfate (up to 64 % in yellow and red pigments), manganese and chromium oxides, lead naphthenate (0.5–2 % in alkyd paints for accelerating the drying), lead oxide Pb_3O_4 (in wall primers for the corrosion preventing), copper chromate, cadmium compounds, etc. Until recently, lead carbonate was used in a white pigment. Paints also contain harmful volatile substances. These include dichloromethane used in some adhesives and as a solvent; butanone (methyl ethyl ketone) used in some inks (for inkjet printers) and as a diluent or solvent; solvent toluene. Other solvents also include benzene, ethylbenzene, xylenes and halogenated hydrocarbons (3- and 4-chloroethylene) [2], ethylene glycol [4]. Some types of glue also contain phenol and formaldehyde. According to the study [4], some paints contain pesticides (biocides, fungicides, insecticides), paint removal fluids (xylenes, butanol, diacetone alcohol), and wood-protective varnishes (chlorinated phenol).

Waste batteries

Waste batteries include accumulators and household batteries. They are among the main sources of heavy metals in the household waste. Waste batteries constitute about 0.02 to 0.25 % of the total household waste mass and about 50 % of hazardous components [6]. Different types of waste batteries contain zinc, manganese, mercury, copper, lead, cadmium, nickel, acids. Many countries have appropriate legislation. EU Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators obliges to have a system for the separate collection of waste batteries. However, many countries do not have an efficiently operating system. Some EU countries have a significant share of batteries not covered by the special collection systems despite legislative and organizational efforts and public concern. According to the study [6], 39 % of batteries in Denmark are mixed with household waste. As of 2014, only about 40 % of batteries were collected in the EU countries [7]. Moreover, according to another study [8], the heavy metals content in many batteries is over the limits set by the before mentioned EU Directive. A detailed analysis of dangerous chemicals in various batteries types is considered below. Zinc-carbon and zinc-chloride batteries contain zinc (casing), zinc and ammonium chloride (electrolyte). Zinc air batteries contain zinc (anode), mercury, potassium hydroxide as an electrolyte.

Alkaline batteries contain zinc (anode) and potassium hydroxide (electrolyte). Silver-zinc batteries contain zinc (anode), potassium or sodium hydroxide (electrolyte). Silver-oxide batteries contain zinc, copper, mercury, nickel, and potassium hydroxide as an electrolyte. Lithium batteries contain lithium (anodic), lithium thionyl chloride $LiSOCl_2$, lithium vanadium pentoxide LiV_2O_5, lithium sulfur dioxide $LiSO_2$, lithium molybdenum trioxide $LiMoO_3$, copper lithium fluoride CuF_2, silver lithium chromate $LiAg_2CrO_4$, or copper lithium sulfide LiCuS (electrolytes), lithium cobalt oxide $LiCoO_2$, lithium manganese oxide $LiMn_2O_4$, and lithium iron phosphate $LiFePO_4$ (cathodes). Lithium-manganese batteries contain lithium (anode), chromium, nickel, or dimethoxyethane (solid electrolytes). Lead-acid batteries contain lead (anode), lead oxide (IV) (cathode), sulfate acid (electrolyte). Alkaline iron-nickel accumulators contain nickel hydroxide $Ni(OH)_3$ (cathode).

Nickel-cadmium accumulators contain cadmium or cadmium hydroxide (anode), nickel oxide hydroxide NiOOH (cathode), potassium and lithium hydroxide (electrolytes). Nickel-metal hydride accumulators contain nickel oxide (cathode), potassium hydroxide (electrolyte), cobalt, zinc. Nickel-zinc accumulators contain zinc (anode), nickel oxide (cathode), potassium and lithium hydroxide (electrolytes). Silver-zinc batteries contain potassium hydroxide (electrolyte). Lithium-ion batteries contain lithium-cobalt oxide $LiCoO_2$ (cathode), lithium salts (lithium hexafluorophosphate $LiPF_6$, lithium tetrafluoroborate $LiBF_4$, lithium perchlorate $LiClO_4$), organic solvents (dimethyl carbonate $CH_3OCO_2CH_3$, diethyl carbonate $CO_3(CH_2CH_3)_2$) as electrolytes, and polyvinylidene fluoride (casing).

Fluorescent lamps and other mercury-containing waste

Many countries do not have the separate collection of fluorescent lamps and other mercury-containing materials from households. Therefore, these wastes are easily released into the environment along with other household waste. One fluorescent lamp contains from 3–6 (compact household lamps) to 50–120 (industrial linear lamps) mg of mercury. The danger of mercury is high due to the high evaporation rate. Hg vapour concentration in the room depends on the evaporation area velocity of air fluxes above the mercury surface, mercury surface conditions, air temperature and other factors. The evaporation rate of metallic mercury is known to be 0.002 $mg/(cm^2 \cdot h)$ at 20°C temperature. However, it increases by 15-18 times at 35–40°C. When a fluorescent lamp containing 80 mg of mercury is broken down, more than 11,000 mercury balls with a diameter of 0.01 cm and total surface of 3.454 cm^2 are formed. In a room volume of 60 m^3, mercury concentration will reach half of daily limit for the household air one hour after the accident (at 20°C temperature). Household thermometers usually contain from 500 to 600 mg mercury. Also, lead oxides are found in lead-silicate glass used in fluorescent lamps.

Waste electrical and electronic equipment (WEEE)

WEEE is relatively new component of household waste with rapidly growing volume all over the world. Electrical and electronic equipment includes household appliances, telecommunication devices, computers, office equipment, telephones, cameras, radios, lighting equipment, electrical tools, toys with electrical or electronic components, and other automatic devices. The large volumes of such waste type are generated due to the rapid technical progress. This results in the short term of the technology use while increasing production and therefore increasing the amount of waste equipment. Polystyrene (42 %), acrylonitrile-butadiene-styrene copolymer (38 %) and polypropylene (10 %) were found in WEEE plastics [9].

The remaining 10 % includes polyethylene, polyvinyl chloride and other polymers. Polymeric WEEE components consist of synthetic macromolecular compounds. Binding substances, plasticizers, and fillers are widely used in these synthetic substances production. These binders can be released into the environment. WEEE plastics may release a lot of substances under certain environment conditions (ultraviolet radiation, temperature, humidity). These include decomposition products, residual amounts of low molecular weight chemicals (monomers, plasticizers, solvents, dyes, stabilizers, degradation products, etc.) having biological activity, and heavy metals (chrome, tin, and antimony).

The main environmental pollutants in WEEE are heavy metals (mainly lead, mercury, cadmium, and hexavalent chromium) and flame retardants: polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs). Arsenic compounds are widely used as semiconductors in household appliances. Cobalt is used in some ceramic materials in medical devices, barium is found in large quantities in cathode ray tubes and digital cameras [10]. Over the time, the dehydrochlorination takes place in polymers based on polyvinyl chloride. This process is intensified at 50–80 °C and highly toxic chlorinated polyaromatic compounds are released [9]. Besides, the compounds of Pb, Cd, Cr, Hg, Br, Sn, Sb are added to plastic of mobile phones as pigments, retardants, fillers or stabilizers. Mobile phones also contain copper (electroplate connections) and zinc (coating of metal components) [11].

Many semiconductors used in almost any electrical or electronic device contain cadmium and arsenic compounds. Transistors contain lead compounds (lead sulphide), and condensers contain polychlorinated biphenyls as well as zinc compounds. Most power cables contain copper, lead, and brominated retardants. Many electrical and electronic devices include batteries – another hazardous component (see the relevant section). According to previous research [3, 12], other sources of hazardous substances are printed circuit boards (mainly lead, chromium, tin and stibium; nickel, arsenic, bromine-containing retardants, phthalates, and phenol are also present in lesser quantities), liquid-crystal displays (arsenic), old monitors, cartridges and toners for printers (polyaromatic hydrocarbons, diethylene glycol, diols, pyrrolidones, furans). Backlight lamps of monitors and network switches contain the luminophores with mercury.

Sometimes, halogen-derivative cooling liquids are also used. Some of the potentially dangerous flame retardants are not included in the list of prohibited. These include chlorinated paraffins, tetrabromobisphenol A (used in epoxy and polycarbonate resins), and hexabromocyclododecane (used in audio and video equipment, cables, etc.) [10]. Phthalates are used in PVC plastics as plasticizers and in resistor conductive paints. The most widely used phthalates are di-2-ethylhexyl phthalate, benzyl butyl phthalate, dibutyl phthalate. Also, Gross et al. [10] consider other chemicals as potentially dangerous: nonylphenol and its derivatives (used in electrical equipment coatings); beryllium compounds (used in optical devices, laser tubes, etc.); antimony oxide (III), arsenic oxide (III) and nickel oxide (III) (all oxides are used as additives in special glass for devices); petrolatum (used in ceramic parts of electrical equipment, fluxes and pastes); biphenyl phosphine oxide (used in X-ray detectors); formaldehyde (used in printed circuit boards, lightings and plywood as a fixing agent).

Cleaning products

Many cleaning products contain quite aggressive substances: phosphates (mainly sodium triphosphate), chlorine, surfactants (sulfonates, alkylphenols and polyethoxylates), sodium hydrochloride, phenols, cresols, nitrobenzene, formaldehyde, etc. [2]. Some cleaning products also contain butanone (methyl ethyl ketone) and tri- and tetrachlorethylene used as solvents and diluents. According to [3], diethylene glycol and nitrobenzene are found in products for surface polishing, as well as acetone and toluene are found in stain removing products. Bleaching agents consist of sodium/ calcium hypochlorite; pipe cleaning products contain sodium triphosphate, hydrochloric acid, and sodium hypochlorite; descaling agents are mixtures of aggressive acids (hydrochloric, phosphoric and oxalic acids). The release of cleaning products residues into the environment may happen either directly when pouring out or along with other household waste. Where domestic sewage treatment is not applied (typically for small municipalities), these substances are released into the environment and pollute underground water.

Medical waste

This waste type includes expired medicines, bandages, used syringes. According to the requirements, medical waste should be burned to avoid biological pollution of the environment. However, medical waste in households is mainly collected along with other household waste.

Residues of pesticides and fertilizers

This is not a very common but a very dangerous waste component. Such residues may appear in the household waste of the countryside where farming is widespread. Pesticides contain substances extremely dangerous to living organisms. These include non-ionic surfactants (acrylic esters of polyoxyethylene) or their mixtures with ionic surfactants (alkyl benzene sulfonates); stabilizers (sodium/calcium alkyl sulfonates); heavy metals (lead arsenate $AsHO_4Pb$, mercury phenyl chloride C_6H_5ClHg, chromium compounds, etc.) [13]. The chemical base of a whole pesticides group is dangerous sulphur-containing and organophosphorus compounds. Besides, dioxins are produced due to pesticides transformation in the environment. Most inorganic fertilizers contain high concentrations of heavy metal compounds. For example, cadmium is found in phosphate fertilizers (up to 300 mg/kg). Chromium and zinc are also found in fertilizers. Fertilizers are also known as a source of nitrates, nitrites and phosphates formation in the environment (after chemical transformations).

Personal hygiene products

Personal hygiene products (including soaps, shampoos, creams, gels, cosmetics and many other products) often contain a large number of different chemicals (preservatives, flavours, antioxidants, etc.) to obtain the desired properties. Some of these compounds are potentially dangerous for a human via direct contact and may pose a significant environmental risk when release into the environment. This issue has not yet been fully explored, but some studies have already been conducted indicating a potential danger. 8 chemicals are identified having the concentrations in personal hygiene products higher the limit: titanium dioxide, polydimethylsiloxane, zinc oxide, butylated hydroxytoluene, diethyl phthalate, octyl methoxycinnamate, butylparaben, and triclosan. Other potentially hazardous substances in many personal hygiene products are as follows: benzophenone-3, methyl- and ethyl-paraben, linalool oxidation products, heavy metals (mainly lead and cadmium in creams), sodium benzoate, formaldehyde, sodium lauryl sulphate, etc. [14]. Aerosols are known to contain chlorofluorocarbons. The authors [15] also investigated the effects of some cosmetic products on living organisms.

CONCLUSION

The analysis shows household waste consisting of large number of hazardous components (fluorescent lamps, batteries, detergent residues, etc.) containing many toxic substances, including heavy metals, phthalates, parabens, sodium lauryl sulphate, phosphates, halogen derivatives of hydrocarbons and many other aggressive, carcinogenic organic and inorganic compounds. The biggest concern is constantly growing waste electrical and electronic equipment as well as that hazardous household waste which is mostly not separated from other waste. If hazardous components are mixed with household waste, then the hazard level of household waste and the operating costs sharply increase. Besides, while most household waste in many countries is delivered to landfills not meeting modern requirements, this poses a great danger to the environment and human health. Therefore, the separation of hazardous components and other household waste is obviously required. This has already been done in many developed countries. However, hazardous household waste is still not collected separately in most countries. Until such measures are implemented, the environmental risk will constantly increase.

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