Hazardous Waste Control and Management: An Overview

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ABSTRACT

Hazardous wastes may become problematic if improper disposal practices are applied. For this reason, behavior of these substances in the environment, assessment of the risks they may pose, and the selection of the most appropriate management strategies for the proper control of these wastes are important. This paper provides a summary of the fate and transport of hazardous substances in the environment, risk assessment, and technology selection for the proper control and management of hazardous waste.

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Introduction

The increasing industrial development all over the world together with globalization comes with its own drawbacks. One of the negative consequences of this trend is the expansion of the hazardous waste problem. Tragedies in the past like Bhopal and Love Canal have shown that hazardous substances and wastes can be tragically problematic when they are not properly taken care of (Varma & Mulay, 2006, Philip et al, 2007). For this reason, understanding their behavior in the environment, assessment of the risks they may pose, and application of selection criteria and methods for the proper control of these wastes are critical tasks. This paper aims to give an overall overview on hazardous substances and risk assessment and control technology selection in the management of hazardous waste.

Hazardous waste can be in the form of solid, liquid or containerized gas, other than radioactive and infectious wastes, by reason of their chemical activity or toxic, explosive, corrosive or other characteristics cause danger to health or the environment whether alone or when coming into contact with other wastes.

Properties of Hazardous Wastes

According to the Council Directive 91/689/EEC of the European Union (EU, 1991) on hazardous waste**,** it means wastes having one or more of the properties listed in Annex III of the corresponding directive. These properties include:

- H1 ‘Explosive’
- H2 'Oxidizing`
- H3-A 'Highly flammable`
- H3-B 'Flammable`
- H4 'Irritant`
- H5 'harmful`
- H6 'Toxic`
- H7 'Carcinogenic`
- H8 'Corrosive`
- H9 'Infectious`
- H10 'Teratogenic` (induce non-hereditary malformations or increase their incidence)
- H11 'Mutagenic`
- H12 Substances & preparations which release toxic gases in contact with water, air or an acid
- H13 Substances & preparations capable of yielding another substance with hazardous characteristics.
- H14 'Ecotoxic`: substances and preparations which present immediate or delayed risks for the environment.

Categories and generic types of hazardous wastes are given in Annex I of Council Directive 91/689/EEC of the European Union. Waste constituents which make a waste hazardous are listed in Annex II.

U.S. EPA definition of hazardous waste is similar to that of EU. According to the U.S. EPA, the following properties make a waste hazardous:

- Ignitability. – Can create fires under certain conditions, are spontaneously combustible, or have a flash point less than 60 °C (140 °F). For example, waste oils and used solvents. Paint wastes, degreasers and solvents are the examples of ignitable hazardous waste.
- Corrosiveness – Acids or bases (pH<2, or >12.5) that are capable of corroding metal containers. Waste rust removers, alkaline cleaning fluids and waste battery acids can be given as examples of this kind of hazardous waste.
- Reactivity – stable under normal conditions. They can cause explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water. Examples are explosives, cyanide plating waste, waste bleaches and oxidizers.

- Toxicity – Harmful or fatal when ingested or absorbed. Mercury, lead, cadmium and some pesticides fall into this category

Sources of Hazardous Wastes

Primary hazardous waste generators include:

- Heavy industries (chemical, leather, paper, metal, etc.)
- Biological waste generators (laboratories and medical hospitals)
- Households (dyes, solvents)
- Transporters (spills and accidents)
- Farmers (pesticides and fertilizers)
- Military (explosives)

In developing economies, small and medium scale industries often play a major role in hazardous waste generation. Typically, these institutions have low level of technology, unskilled management, unspecialized workers, lack of modernization and poor environmental performance. There are substantive risks from occupational and environmental exposure.

Quantity of Hazardous Wastes

Estimated hazardous waste generation in the world is more than 400 million tons/yr (United Nations Environmental Programme [UNEP], Geo 2000). Hazardous waste generation in Europe has significant contributions to this value. EU member countries have a hazardous waste generation of 65 million tons in 2004. EECCA (Eastern Europe, Caucasus and Central Asia) is the most problematic region (near 200 million tons in 2004), where Russian Federation itself is the largest generator (about 150 million tons in 2004). These countries have started to decrease their hazardous waste generations after the Kiev Conference (2003).

Control of hazardous waste requires an integrated approach including the time frame beginning from the production of hazardous substance to the end of the post closure monitoring of the disposed waste. Being reduction of the hazardous waste (Substitution of raw materials, manufacturing process changes, etc.) and recovery and reuse of the waste materials are the primary steps, management of final waste products is applied based on the waste characteristics and results of the risk assessment procedure. Figure 1 shows the steps for the control of hazardous wastes.

Fate and Transport of Hazardous Waste

Fate and transport of hazardous waste gain importance immediately after the accidental or controlled disposal of the waste to the environment. The form of contaminant release (solid, liquid, gaseous or mixture) is crucial because the fate and transport mechanisms directly depend on the type of the waste.

Figure 1. Steps for the Control of Hazardous Waste

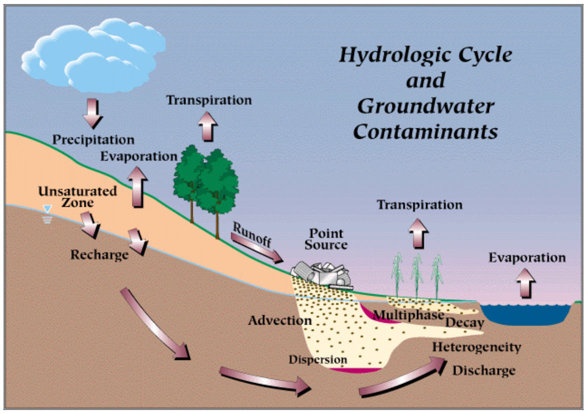
Transport of the waste refers to the movement of the waste molecules in a medium and is affected by the waste properties, type of medium and some external parameters such as the presence volatilization by winds, precipitation, gravitational settling and buoyant rise. On the other hand, the fate of pollutants explains the transformations within the waste constituent or within the medium, and changes in the amount and concentration of the contaminant (LaGrega et al, 2001). Waste in the environment ceases to pollute when:

- It is assimilated by biological processes;
- It is chemically changed into harmless products; or
- It is diluted to an acceptable level.

Fate and transport processes of the waste in an aquatic environment are mainly dissolution, dilution and diffusion, volatilization to atmosphere, photolysis, hydrolysis, sorption on sediments, deposition and bio-concentration. Fate and transport processes in a terrestrial environment are evaporation to atmosphere, infiltration to soil and groundwater, advection and dispersion in water bodies or groundwater, photolysis, oxidation, sorption and complex formation on soils (Öman & Rosqvist, 1999, Tchobanoglous et al, 1994). Figure 2 shows the principal fate and transport mechanisms of contaminants.

A contaminant release can occur either in controlled conditions or by accident. The aim of controlled releases is to minimize harm to the environment. Accidental releases are not under the direct management of the unit operators. They include, for example, puffs from incinerators, a break in a pipeline, or leak from an underground storage tank. Table 1 shows types of releases from different sources.

Figure 2. Hydrological Cycle and Groundwater Contaminants



(Source: Oak Ridge National Laboratory)

Table 1. Major Sources of Hazardous Waste Release

Hazardous waste disposal sites	Impoundments
	Landfills
	Septic tanks
	Underground injection wells
Materials handling and storage	Underground storage tanks
	Above ground storage tanks
	Material stockpiles
	Material transfer and transport
Mining	Coal mining
	Non-coal mining
	Oil, gas and geothermal wells
Other	Household operations
	Atmospheric discharges
	Agricultural pesticides

Health Issues and Risk Assessment

Disposal of hazardous wastes to the environment creates environmental and health concerns. Evaluation of health aspects and risk assessment is a vital step in controlling and managing hazardous waste. Health effects of a hazardous substance depend on various parameters such as exposure pathway, time of exposure and amount of intake. A chemical can be exposed by three different pathways: (1) taken via oral route (ingestion), (2) by inhalation or (3) skin contact. According to the duration of exposure, their impacts can be named as follows:

- Acute – one day
- Sub-acute – ten days
- Sub-chronic – two weeks to seven years
- Chronic – seven years to lifetime

Types and severity of adverse health effects caused by hazardous substances change with respect to the type of chemical, exposure pathway, exposure period and exposed amount of chemical. Typical adverse health effects include the following ones:

- Hepatic
- Neurological
- Hematologic
- Reproductive
- Respiratory
- Gastrointestinal
- Endocrinological
- Immunological
- Muscular
- Renal
- Dermatological

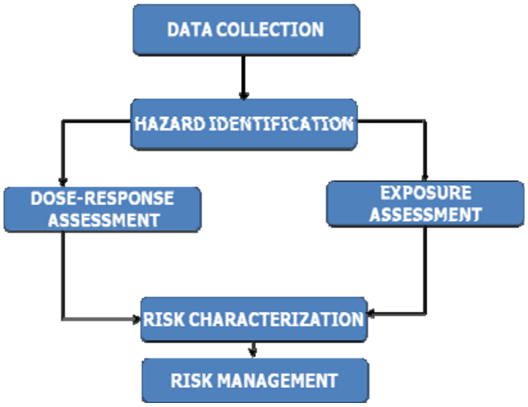
Risk assessment is both a qualitative or quantitative evaluation of the environmental and health risk resulting from exposure to a chemical or physical agent (pollutant). It combines exposure assessment results with toxicity assessment results to estimate risk.

Risk assessment can be used to:

- Conduct a baseline analysis of a site or facility to determine the need for remedial action and extent of clean up required;
- Develop clean up goals for contaminants;
- Construct what-if scenarios;
- Evaluate existing and new technologies for effective control, or migration of hazards and risks;
- Select sites for hazardous facilities such as incinerators and waste storage; or
- Provide a scientific basis for corporate risk-reduction and management program.

Moreover, risk assessment is performed in several successive steps as presented in Figure 3.

Figure 3. Phases of Risk Assessment



1. *Date collection*

The data are generally collected from studies of occupational exposures of workers, community exposures, university research, medical records, and toxicology data.

2. *Hazard identification*

It is the process of determining if a particular chemical is causally linked to a particular health effect such as cancer or birth defect.

3. *Dose-response assessment*

It is the process of characterizing relation between dose of an agent and the incidence of an adverse health effect. Relationships vary with respect to the conditions. There are two types of responses: non-threshold effects (for carcinogens) and threshold effects (for non-carcinogens) (LaGrega et al, 2001). It is not possible to determine a threshold for a carcinogen since response rate for a carcinogenic substance is in direct relation with the concentration of the chemical exposed (Figure 4).

4. *Exposure assessment*

It involves the determination of magnitude, frequency, duration, and routes of exposure of human populations and ecosystems.

5. *Risk characterization*

Toxicology and exposure data are combined to obtain a qualitative or quantitative expression of risk.

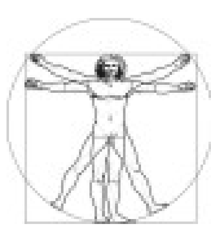
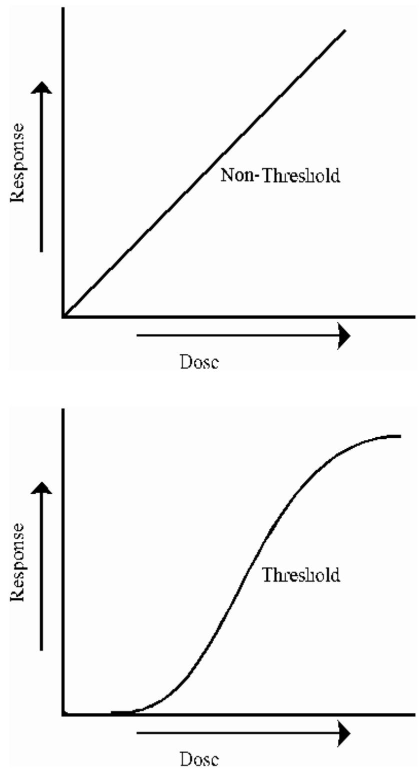


Figure 4. Dose-response Curves of Carcinogenic and Non-carcinogenic Substances



Selection of Hazardous Waste Control Technologies

Control of hazardous waste occurs by changing the properties of the waste material so that it is less hazardous or not hazardous at all, or entrapping the waste material to minimize the reach of hazardous chemicals to the environment and humans. The techniques used for the control of hazardous waste are numerous. A classification of these methods and a list of common techniques are given in Table 2.

Process selection for the control of hazardous waste should be based on three different criteria:

- *Nature of Waste:* The physical form of the waste (liquid, emulsion, slurry, sludge, powder, bulk solid) affects the selection of control technology. Chemical composition, physical properties, components of hazardous waste within the waste material, volume/mass ratio and source variability are the other factors important for process selection. Water solubility is a physical parameter which is of special concern. Liquids which are soluble in water are called “aqueous liquids”. Liquids not soluble in water are denoted as “non-aqueous phase liquids” (NAPLs) and these substances are difficult to control in case leakage to subsurface and groundwater is present. Different techniques are applied for the liquids denser than water (DNAPLs) and liquids lighter than water (LNAPLs).

- *Treatment Options:* Availability of treatment options, current and future needs on the case, treatment goals, regulatory requirements for the area and efficiency and reliability of the techniques for different cases should be concerned while choosing the control technology.
- *Technical Adequacy:* Application of separate or combined technologies, the need for pretreatment, sensitivity of the technology to changes and its potential for modifications are the concerns for technology selection.

Table 2. Common Hazardous Waste Control Technologies

Physicochemical Processes	Air Stripping
	Soil Vapor Extraction
	Soil Washing
	Carbon Adsorption
	Steam Stripping
	Supercritical Fluids
	Membrane Processes
	Chemical Oxidation
Biological Methods	In-situ Bioremediation
	Ex-situ Bioremediation
Stabilization-Solidification Techniques	Macro-encapsulation
	Microencapsulation
	Absorption
	Adsorption
	Precipitation
	Detoxification
	Vitrification
Thermal Methods	Incineration
Land Disposal	Landfilling

Conclusions

The methods for hazardous waste management strategies are straightforward. Hazardous materials must be detoxified, diluted to harmless levels, or completely isolated from the environment. However, difficulties arise in the areas of assessment of health and environmental impacts, technology selection, process integration, and application constraints. A summary of fate and transport issues, risk assessment and selection of control technologies were given in this paper in order to ease the solution of these difficulties.

Proper disposal of hazardous waste is important in protecting public and human health. Application of cradle to grave management strategy is a suitable way for the control of hazardous waste upon its generation. In this strategy, a lifetime approach to hazardous substances is made starting from the waste generation and including assessment of risks, applying control technologies, disposal and post disposal care. A successful hazardous waste management practice depends on the application of this integrated approach.

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