Effect of Chemicals on Environment and Health – A Review

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Abstract— *Chemical diversity, abundance and hazardousness are one of the major environmental challenges of today. On the contrary to biological diversity, chemical diversity can be problematic from an environmental point of view. There is not sufficient knowledge to provide protection for human health and the environment against all these chemicals, which according to the European Inventory of Existing Commercial Chemical Substances (EINECS) is slightly above 100.000 (Ex ECB, 2011). Plastic polymers and products, which are the focus of this paper, are extremely diverse, both in terms of chemical composition, properties and possible applications. Several hazardous substances may be released during the life cycle of a plastic product; and considering the large and growing global consumption of plastic products, and their omnipresence and persistence in the environment, there is a need for assessing the hazards and risks of this large material group.This paper presents the study of the environmental and health hazards of chemicals in plastic polymers and products from a toxicological perspective.*

Keywords—Biological Diversity; Plastic polymers; Chemical composition

I. INTRODUCTION

Plastics are important in our society and offer many benefits for human health and the environment, for instance (PlasticsEurope, 2009; Andrady and Neal, 2009):

• Plastic packaging protects food and goods from getting wasted and/or contaminated and thereby saves resources.
• The light weight packaging material (due to high strength-to-weight ratio) saves fuel and decreases emissions during transportation.
• Plastic water supply systems and storage containers/tanks provide clean water.
• Light plastic materials (replacing metals) in cars and aircraft save fuel and decreases emissions.
• Efficient plastic insulation materials in buildings save energy and provide climate protection.
• Plastic protective clothing and safety equipment (e.g. fire proof materials, helmets, air bags) protects form injury.
• Plastic products for medical applications are very important and contribute to improved heath (e.g. blood pouches, tubings, disposable syringes, prosthesis).
• Solar heaters and solar panels, in parts made of plastics, provide renewable energy.

1.1. Plastic degradation

The persistence of plastic waste is another problem. Most plastic polymer types are resistant to biodegradation, i.e. degradation by microorganisms, and the two most abundant ones, polyethylene and polypropylene, are extremely resistant to biodegradation (Nicholson, 2006). In a polyethylene polymer only 0.1% of the carbon will be transformed into CO2 per year by biodegradation under optimal laboratory exposure conditions, according to Andrady (1998). There are a few biodegradable plastics which today only have a minor, but growing, share in the plastic market. Not all of them, however, are completely biodegradable in the natural environment (Rudnik, 2008; O´Brine and Thompson, 2010). Non-biodegradable polymers can be degraded by heat, oxidation, light, ionic radiation, hydrolysis and mechanical shear, and by pollutants such as carbon monoxide, sulphur dioxide, nitrogen oxide and ozone (Ravve, 2000). This causes the polymer to get brittle, to fragment into small pieces and to release degradation products. Different degradation mechanisms exist and which of them that will dominate depends on the polymer type. Chain scission involves breaking the chemical bonds in the polymer molecule, and is often random, but for some polymers it proceeds at the polymer end chains and the initial monomers are broken off, a process called depolymerisation (Alger, 1997; Braun, 2005).

II. PLASTIC COMPOSITION AND HAZARDOUS CHEMICALS

Plastic products are made from plastic polymers to which additives are added to enable processing and/or to give certain desired properties for a specific application (OECD, 2004). The polymers are made by polymerising monomers into macromolecular chains. These monomers are almost exclusively

derived from non-renewable crude oil. Approximately 4% of world oil demand is used as raw materials for plastic production (British Plastic Federation, 2011). Other substances (besides monomers) are often needed for polymerisation to occur, for instance initiators, catalysts, and depending on manufacturing process, solvents may also be used. The resulting plastic polymer can be blended with different additives, for instance plasticisers, flame retardants, heat stabilisers, antioxidants, light stabilisers, lubricants, acid scavengers, antimicrobial agents, anti-static agents, pigments, blowing agents and fillers, and is finally processed into a plastic product. There are many different plastic polymers and several thousand different additives, which results in an extremely large variation in chemical composition of plastic products (Rosato, 1998).

2.1 Exposure

For workers in the plastics industry the main route of exposure to toxic substances is byinhalation and absorption through the lungs, which according to Lokensgard and Richardson (2004) accounts for nearly 90 percent of the toxic symptoms observed in the plastics industry. This is quite expected since many of the hazardous chemicals used in plastic production are volatile organic compounds (VOCs). The VOCs are mainly emitted during the production phase, but also during the use and the end of life phase. This causes indoor air pollution which may be harmful for human health. VOCs also contribute to elevated ground-level ozone levels which may damage vegetation, can irritate the respiratory system, aggravate asthma and lung diseases, cause permanent lung damage, and affect the immune system (US EPA, 2011).

For consumers exposure to chemicals released from a plastic material during the use phase may vary greatly between different products. The exposure may for instance come from indoor air, food, water, and skin contact, but in most cases this is not likely to be so large that it will result in adverse effects. However, the actual exposure does not come from only one product but from a whole array of different plastic products, and exposure to a mixture of chemicals will often be continuous. Chemicals used in plastics have been detected in humans. Mainly presence of phthalates and bisphenol A, (reviewed by Koch and Calafat, 2009) and brominated flame retardants (Thomsen et al., 2010) have been studied. The main part of available research on chemicals associated with plastics is focusing on these substances.

2.2 Effects

Effects from chemical exposure can be studied from a human toxicological perspective and an ecotoxicological perspective. For the laboratory studies in this thesis aquatic ecotoxicological tests have been used to study effects. In the field of ecotoxicology there are many ways to study effects of chemicals by using biological assays. This can be done by using:

- laboratory tests or field studies,
- *in vivo* (within a living organism) tests, which is most common, or *in vitro* (isolated organ, tissue, cell or biochemical system) tests,
- acute or chronic tests on a variety of test organisms (aquatic or terrestrial),
- species representing one or several trophic levels,
- single species or communities,
- various toxic endpoints to study different effects,
- standardised test procedures or test procedures adapted to a specific exposure scenario or ecosystem.

As all approaches have their pros and cons and none of them, of course, cover all aspects, it is important to be aware of the limitations with the chosen method when making assessments and predictions. The simplest and least time consuming tests are usually aquatic acute toxicity tests in laboratory on bacteria, algae or small invertebrates. These show the effect of short term exposure, in terms of e.g. inhibition of growth, immobility or death, and require presence of toxicant(s) in relatively high concentrations. These tests can be advantageous for screening purposes, especially when the chemical composition of the test medium is not known, and thereby not either the anticipated toxic response. Chronic tests are usually more sensitive and ecologically relevant, since exposure to toxicants in the environment usually occurs in lower concentrations during a longer time period. Examples of other toxic effects include carcinogenicity, reproductive toxicity, mutagenicity, and various effects caused by endocrine disruption.

III. HAZARD AND RISK ASSESSMENT

Hazard and risk assessments are used to assess the environmental and/or health hazards and risks of chemicals. Below hazard and risk assessment terminology is presented according to the harmonised definitions made by International Programme on Chemical Safety (IPCS, 2004). The definitions are very slightly paraphrased, and "agent or situation" is replaced with "chemical".

A ***hazard*** is the inherent property of a chemical having the **potential to cause adverse effects** when an organism, (sub)population, or ecosystem is exposed to that chemical.

A ***risk*** is the **probability of an adverse effect** in an organism, (sub)population, or ecosystem caused under specified circumstances by exposure to a chemical.

3.1 Hazard assessment

It is a process designed to **determine the possible adverse effects** of a chemical to which an organism, (sub)population, or ecosystem could be exposed. It includes two steps:

a) ***Hazard identification*** is the identification of the type and nature of adverse effects that a chemical has an inherent capacity to cause in organism, (sub)population, or ecosystem.

b) ***Hazard characterization*** is the qualitative and, if possible, quantitative description of the inherent property of a chemical having the potential to cause adverse effects. If a quantitative description is possible it should include a dose–response assessment and its strengths and weaknesses.

3.2 Risk assessment

It is a process intended to calculate or **estimate the risk** to a given target organism, (sub)population, or ecosystem **following the exposure** to a chemical. A risk assessment includes four steps, of which the first two are from the hazard assessment:
a. Hazard identification
b. Hazard characterization (related term: Dose–response assessment),
c. ***Exposure assessment*** is the evaluation of the exposure of an organism, (sub)population, or ecosystem to a chemical (and its derivatives).
d. ***Risk characterisation*** is the qualitative and, if possible, quantitative determination of the probability of known and potential adverse effects of a chemical to occur in a given organism, (sub)population, or ecosystem, under defined exposure conditions.

Hazard and risk assessment methods, e.g. the European Union Technical Guidance Document (European Commission, 2003), are very comprehensive and have been developed for assessing single chemicals. Risk assessments are only available for a few of the chemicals used to make plastics. This paper mainly comprises the hazard identification step and parts of the hazard characterisation step.

IV. HAZARD RANKING MODEL

There are several ranking and scoring systems for chemicals (evaluated by Davis et al., 1994), but there is no consensus on which of the methods that is the most effective. A new hazard ranking method based on hazard classifications was developed for this study. The EU classification, labelling and packaging (CLP) regulation was chosen because it contains harmonised classifications, and is based on the UN Globally Harmonized System (GHS) (European Parliament and Council, 2008; UN, 2009). Therefore, the model and the data in the model can be regarded as having an almost global validation. No previous ranking method was available for the GHS or CLP. In the ranking model the CLP hazard classes for environment and health hazards, with accompanying categories, were sorted into five levels of hazards (*I-V*). The hazard classes and categories sorted as level *V* were: carcinogenicity, mutagenicity and reproductive toxicity (categories 1A & B), and hazardous for the ozone layer. Those sorted as level *IV* were: mutagenicity (cat. 2), acute toxicity (cat. 1 & 2), respiratory/skin sensitisation, specific target organ toxicity – single/repeated exposure, and hazardous to the aquatic environment (chronic cat. 1 & 4). Each level was assigned a rough hazard grade, increasing with a factor of 10 for each level of hazard (*I-V*). The hazard grades for each classification that a substance has were summarised to create a hazard score for the substance.
In the ranking of the polymers only the basic building blocks that define the polymer, i.e. the monomers (with a few exceptions), were included. These can not be changed without changing the polymer. Other chemicals needed for polymerisation to occur, such as catalysts, solvents, etc., were not included because they would add to much variability to the ranking. These substances have, however, been presented and discussed separately. Additives that are compounded with the polymer to make different plastic products were excluded because of the extreme diversity and variability.

The hazard score for the substance (in this case the monomer) was multiplied with the weight fraction of the monomer in the polymer. Finally the sum of the hazard scores for all monomers included in the polymer type was calculated and a hazard ranking of the different plastic polymers was made. The hazard ranking model works well for separating the different levels of hazards, but is rough both in terms of hazard levels and hazard grades, and could need some refinement. The hazard scores should, therefore, not be regarded as absolutely true figures but rather as a way to enable an approximate relative ranking, and to identify presence of hazardous substances.

A valuable contribution to the Globally Harmonised System would be the development of a harmonised grade for each hazard classification. These grades could be used to facilitate comparisons between different substances and could be used in hazard and risk assessments when many substances are involved.

4.1 Initial assessments

The assessments made for the different polymers do not cover the strict definition of hazard assessments (described in 1.8) and are, therefore, called initial assessments. These mainly comprise assessments of non-classified substances based on

1) available information from OECD SIDS Initial Assessment Reports of substances,
2) assessments of other hazardous substances used than monomers, and
3) comparisons between hazard rank and global annual production.

Global annual production was used as a rough measure for quantifying the hazard in order to identify which polymers should be prioritised for further risk assessments. Exposure and effect assessment have been discussed but were not possible to include in this study. Even when dealing with single chemicals, such assessments can be a hard challenge, although easy compared to assessing complex products such as plastic products.

V. RESULTS AND DISCUSSION

This section summarizes and discusses results.

5.1. Acute toxicity from product leachates

Acute toxicity was seen in all toxicity studies in approximately 30% of the samples.

5.2 Toxicity of plastic products and synthetic textiles

Twenty-eight of the leachates from the 83 studied plastic products and synthetic textiles showed acute toxicity to *Daphnia magna* (Table 1). This represents 33.7% of the tested 20 products.
The toxic products are shown in Figure 1 given below.
The applications for the products varied, and no specific product category was tested. Examples of product categories include drinking water and ground pipes, floors, fillers, mattress, household articles (e.g. food and water containers, table cloths, plates), articles 21 intended for small children (toys, floating aid and diapers), garbage bag, rain and skin protection, and synthetic textiles (e.g. clothes and furniture and technical fabrics).

Fig 1 Plastic products which cause toxic

The sample size for the different product categories is not large enough to draw general conclusions for respective product category. However, a few patterns have been noted.
Considerably many leachates from products intended for children (5/13) were toxic. These include a floating ring, arm pads for floating, children's handbag, a bath tub squirt toy, and a diaper (excluding the absorbing core and top sheet). None of the 12 leachates from articles for food or drinking water contact were acutely toxic, an outcome which was expected since there are regulations for food contact materials. Among the synthetic textiles technical fabrics and furniture fabrics were among the most toxic ones, and the fabrics in the clothes category were less toxic.

Table 1. The 28 toxic plastic product [I, II] and synthetic textile [III] leachates and their 48-h EC50s for *Daphnia magna* (modified from papers I-III).

Product	Plastic type	48 h EC50s g plastic/L		TIE indication	Leaching test
		Repl 1	Repl 2	of toxicant	
Plastic products					
I. Artificial leather, brand S	Plasticised PVC	8	8	organics (& metals)	24 h shaking 22°C
I. Artificial leather, brand,G	Polyurethane	38	31		24 h shaking 22°C
I. Artificial leather, brand M	Plasticised PVC	26	22	organics (& metals)	24 h shaking 22°C
I. Floor	Platicised PVC with polyurethane surface	54	50		24 h shaking 22°C
I. Children's handbag	Polyurethane	44	54		24 h shaking 22°C
I. Bath tub squirt toys	Plasticised PVC	≈ 100	59		24 h shaking 22°C
I. Inflatable bathing ring	Plasticised PVC	71	75		24 h shaking 22°C
I. Table cloth	Plasticised PVC	62	76		24 h shaking 22°C
II. Watering can	High-density-polyethylene	17	24		3 d diffusion 50°C
II. Laboratory gloves	Plasticised PVC	2	4	metals	3 d diffusion 50°C
II. Boat fender	Plasticised PVC	21	11	organics	3 d diffusion 50°C
II. Arm pads for floating	Plasticised PVC	79	70	organics	3 d diffusion 50°C
II. Rain poncho	Plasticised PVC	172	160	organics (& metals?)	3 d diffusion 50°C
II. Wet room wall carpet	Plasticised PVC	235	219		3 d diffusion 50°C
II. Super epoxy (filler) [a]	Epoxy (cured)	10	2	organics	3 d diffusion 50°C
II. Marine epoxy (filler) [a]	Epoxy (cured)	9	6	organics	3 d diffusion 50°C
II. Quick epoxy glue [a]	Epoxy (cured)	44	39		3 d diffusion 50°C
II. Laminating epoxy [a]	Epoxy (cured)	>80	27		3 d diffusion 50°C
II. Epoxy putty (sealant) [a]	Epoxy (cured)	114	99		3 d diffusion 50°C
Synthetic textiles					
III. Awning cloth [b]	Polyacrylonitrile (acrylic) impregnated with polytetrafluorethylene (PTFE; Teflon®)	1	1	organics	3 d diffusion 50°C
III. Furniture fabric	Polypropylene	4	3		3 d diffusion 50°C
III. Mesh fabric [b]	Plasticised PVC coated polyester (PET)	7	8	organics	3 d diffusion 50°C
III. Baby diaper outer material [c]	Polypropylene and polyethylene	75	68		24 h shaking 22°C
III. Knitted muffler	Polyacrylonitrile (acrylic)	108	131		3 d diffusion 50°C
III. Furniture fabric	Polyacrylonitrile (acrylic; 73%), polyester (27%)	176	185		3 d diffusion 50°C
III. Curtain	Polyamide (nylon)	172	145		3 d diffusion 50°C
III. Wool imitation fabric	Polyacrylonitrile (acrylic)	124	180		3 d diffusion 50°C
III. Stretch pants (golden)	Polyester (92%), thermoplastic polyurethane (elastane; 8%)	210	201		3 d diffusion 50°C

[a] Cured epoxy resin
[b] Technical fabric
[c] The non-woven material was tested, excluding the absorbing core and covering top sheet. Some unspecified elastic material was also present.

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