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Bio-Degradable Plastics Impact On Environment

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ABSTRACT

The potential of biodegradable polymers and more particularly that of polymers obtained from renewable resources such as the polysaccharides (e.g., starch) have long been recognized. However, these biodegradable polymers have been largely used in some applications (e.g., food industry) and have not found extensive applications in the packaging industries to replace conventional plastic materials, although they could be an interesting way to overcome the limitation of the petrochemical resources in the future. The fossil fuel and gas could be partially replaced by greener agricultural sources, which should participate in the reduction of CO2 emissions. Bio-based and biodegradable plastics can form the basis for environmentally preferable, sustainable alternative to current materials based exclusively on petroleum feed stocks. These bio-based materials offer value in the sustainability/life-cycle equation by being a part of the biological carbon cycle, especially as it relates to carbon-based polymeric materials such as plastics, water soluble polymers and other carbon based products like lubricants, biodiesel, and detergents. Identification and quantification of bio based content uses radioactive C-14 signature. Biopolymers are generally capable of being utilized by living matter (biodegraded), and so can be disposed in safe and ecologically sound ways through disposal processes (waste management) like composting, soil application, and biological wastewater treatment. Single use, short-life, disposable products can be engineered to be bio-based and biodegradable.

KEYWORDS: CO2 emissions, life-cycle equation , biodegraded. Plastics

I. INTRODUCTION

The potential of biodegradable polymers and more particularly that of polymers obtained from renewable resources such as the polysaccharides (e.g., starch) have long been recognized. However, these biodegradable polymers have been largely used in some applications (e.g., food industry) and have not found extensive applications in the packaging industries to replace conventional plastic materials, although they could be an interesting way to overcome the limitation of the petrochemical resources in the future. The fossil fuel and gas could be partially replaced by greener agricultural sources, which should participate in the reduction of CO2 emissions.Bio-based and biodegradable plastics can form the basis for environmentally preferable, sustainable alternative to current materials based exclusively on petroleum feed stocks. These bio-based materials offer value in the sustainability/life-cycle equation by being a part of the biological carbon cycle, especially as it relates to carbon-based polymeric materials such as plastics, water soluble polymers and other carbon based products like lubricants, biodiesel, and detergents. Identification and quantification of bio- based content uses radioactive C-14 signature. Biopolymers are generally capable of being utilized by living matter (biodegraded), and so can be disposed in safe and ecologically sound ways through disposal processes (waste management) like composting, soil application, and biological wastewater treatment. Single use, short-life, disposable products can be engineered to be bio-based and biodegradable. Polymer materials have been designed in the past to resist degradation. It is widely accepted that the use of long-lasting polymers for short-lived applications (packaging, catering, surgery, hygiene), is not entirely adequate. Most of the today's synthetic polymers are produced from petrochemicals and are not biodegradable. Furthermore, plastics play a large part in waste management, and the collectivities (municipalities, regional or national organizations) are becoming aware of the significant savings that the collection of compostable wastes would provide. Valorizing the plastics. Unfortunately, the properties of plastic that make it so valuable also make its disposal problematic, such as its durability, light weight and low cost. In many cases plastics are thrown away after one use, especially packaging and sheeting, but because they are durable, they persist in the environment. If plastic reaches the sea, its low density means it tends to remain on the surface.

1.1 Classes of biodegradable plastics

The classes of biodegradable plastics considered, in terms of the degradation mechanism, are:

1) Biodegradable
2) Compostable
3) Hydro-biodegradable
4) Photo-biodegradable
5) Bioerodable

These definitions of degradation are used throughout the report to describe the degradation processes of the ‘biodegradable plastics’ currently available or under development. Definitions of these degrading mechanisms for different materials are provided below.

Biodegradable

The failure of early ‘biodegradable’ plastics to properly degrade led to the American Society of Testing and Materials (ASTM) creating definitions on what constitutes ‘biodegradability’. The ASTM definition, updated in 1994 (ASTM Standard D-5488-84d), has led to the establishment of labelling terminology for packaging materials. The ASTM defines ‘biodegradable’ as: “capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardized tests, in a specified period of time, reflecting available disposal condition.”

Biodegradation is degradation caused by biological activity, particularly by enzyme action leading to significant changes in the materials chemical structure. In essence, biodegradable plastics should break down cleanly, in a defined time period, to simple molecules found in the environment such as carbon dioxide and water Biodegradation rates are highly dependent on the thickness and geometry of the fabricated articles. While rapid breakdown rates are often quoted these generally apply to thin films. Thick-walled articles such as plates, food trays and cutlery can take up to a year to biologically degrade.

Compostable

Compostable biodegradable plastics must be demonstrated to biodegrade and disintegrate in a compost system during the composting process (typically around 12 weeks at temperatures over 50°C). The compost must meet quality criteria such as heavy metal content, ecotoxicity, and no obvious distinguishable residues caused by the breakdown of the polymers. Compostable plastics are a subset of biodegradable plastics. ‘Compostable’ is defined by the ASTM as: “capable of undergoing biological decomposition in a compost site as part of an available program, such that the plastic is not visually distinguishable and breaks down to carbon dioxide, water, inorganic compounds, and biomass, at a rate consistent with known compostable materials (e.g. cellulose).”

Hydro-biodegradable and Photo-biodegradable

Hydro-biodegradable and photo-biodegradabe polymers are broken down in a two-step process - an initial hydrolysis or photo-degradation stage, followed by further biodegradation. Single degradation phase ‘water-soluble’ and ‘photodegradable’ polymers also exist.

Bio-erodable

Many polymers that are claimed to be ‘biodegradable’ are in fact ‘bioerodable’ and degrade without the action of micro-organisms – at least initially. This is also known as a biotic disintegration, and may include processes such as dissolution in water, ‘oxidative embrittlement’ (heat ageing) or ‘photolytic embrittlement’ (UV ageing).

1.2. Plastics in the environment

Consumption, of course, leads to waste, and in the case of plastics, large volumes of extremely persistent waste are created. The problems with plastic waste are many.

1.2.1. Plastic waste management

The largest plastic waste fraction goes to landfill. For Europe the average is around 50% (Plastics Europe, 2009). Landfill space is scarce in many countries which lead to emissions from transportation over long distance, and increasing the landfill area may require valuable land. Emissions from landfills may also contaminate ground and surface water.

Alternatives to land filling are mechanical recycling, energy recovery, or chemical recovery. The heterogeneity of plastic products and types obstructs recycling, or makes plastic recycling difficult in many cases (Hopewell, 2009). Recycling is possible for some fractions, but in order to get a similar, or not a too low grade product, a homogenous fraction is required, which requires labour intensive sorting.

Plastic waste for recycling is often transported over long distances, for instance exported from the industrial to the developing countries, particularly in Asia (India, 2010). Energy recovery by incineration of plastic waste in Europe has a larger share (30 %), than recycling (20%) (India, 2009). Combustion of plastics may cause emissions of hazardous substances and contributes to global warming (since most plastics are fossil based).

1.2.2. Plastic waste in the marine and terrestrial environment

A very large fraction of plastic waste ends up as litter in the terrestrial and marine environment. The marine environment is especially exposed and has been most widely studied. Large and increasing amounts of plastic products, debris, fragments and even micro particles are found in the open ocean, on the surface, in the deep ocean and ocean bed, in coast lines, in sediments, and in organisms (Barnes et al., 2009; Thompson et al., 2004).

For instance, in surface trawl studies (net mesh size 330 µm) plastics were found at 55 of 76 locations in the Kuroshio Current area (North Pacific), in quantities ranging 0–3.52x106 pieces/km2, with a mean abundance of 1.74x105 pieces/km2 (Yamashita, 2007); and near the central pressure cell of the North Pacific subtropical high a mean abundance of 3.34x105 plastic pieces/km2 were found (Moore et al., 2001).

The particle sizes 1-3 mm constituted 62% of all marine plastic pieces (Yamashita, 2007). Even smaller sizes of plastic pieces ≤20 µm in sediment have been reported by (Thompson et al., 2004; Ng and Obbard, 2006).

1.2.3. 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).

In the marine environment degradation is especially slow, since degradation mainly is likely to occur by solar radiation and slow thermal oxidation (Gregory and Andrady, 2003). This means that the time frame for complete degradation is very long and could, in some situations, be several hundred years.

1.3. Regulations for hazardous chemicals in articles/plastic products

The European chemicals legislation, REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) aims to improve the protection of human health and the environment through an earlier and improved identification of the intrinsic properties of chemical substances (European Commission, 2011a). Provisions are laid down for substances and preparations and shall also apply to the use of these chemicals in articles (European Parliament and Council, 2006) and, thereby, to some extent cover chemicals in articles.

For the finished article the requirements are not as far reaching as for single substances and preparations. Monomers and polymers are less strictly regulated than other chemicals, since there are some exemptions from the general requirements in REACH (ECHA, 2008). However, in the European Union there are restrictions for use and even bans for some substances in certain product groups. The ones applicable to plastics and plastic products are for instance:

- The phthalate plasticisers DEHP (di(2-ethylhexyl) phthalate), DBP (dibutyl phthalate) and BBP (benzyl butyl phthalate) in toys and child care articles, at concentrations >0.1% by mass (European Parliament and Council, 2006).
- The phthalate plasticisers DINP (diisononyl phthalate), DIDP (diisodecyl phthalate) and DNOP (di-n-octylphthalate) in toys and child care articles which can be placed in the mouth (concentrations >0.1% by mass; European Parliament and Council, 2006).
- Cadmium for giving colour to plastics, or used as stabilisers in PVC (European Parliament and Council, 2006).
- The flame retardants polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) in electronic products (RoHS-directive; European Parliament and Council, 2003).
- Bisphenol A in baby bottles (from 1st March 2011; European Commission, 2011b).

Recently (17 February 2011), the European Commission announced a ban on use of six substances which is to be effective within three to five years, unless an authorisation has been granted to individual companies for their use (European Commission, 2011c). Four of them are used in plastics, i.e. the phthalate plasticisers DEHP, BBP and DBP, mainly used in PVC, and 4,4' methylenedianiline (MDA) used as a curing agent for epoxy resins.

Also by international conventions there are regulations of use for certain substances. The Stockholm Convention on Persistent Organic Pollutants (POPs) requires the parties of the convention to eliminate or reduce the use of the listed POPs. Of the chemicals used in plastics some of the brominated flame retardants are listed.

There is also a directive laying down the basic rules necessary for testing migration (release) from plastic materials and articles intended to come into contact with foodstuffs (European Council, 1982).

1.4. 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).

Also the amount of additives used is highly variable. PVC is the plastic type that requires by far the most additives. Of the world production of additives PVC alone accounts for 73% by volume, polypropylene and polyethylene account for 10 %, and styrenics account for 5%. Many additives are hazardous for human health and the environment.

Some are especially hazardous, for instance brominated flame retardants used to retard ignition and prevent fire from spreading; some phthalate plasticizers mainly used to make PVC flexible; and lead heat stabilizers used to prevent degradation of PVC during processing (Murphy, 2001). Several polybrominated flame retardants are very persistent, very bioaccumulating and toxic, and are listed in the Stockholm Convention on Persistent Organic Pollutants (POPs).

Among the phthalate plasticisers the most hazardous ones, i.e. BBP, DEHP and DBP, are classified as toxic for reproduction (category 1B). BBP is also very toxic to aquatic organisms with long lasting effects (European Parliament and Council, 2008; European Commission, 2009).

In addition, these phthalates, as well as DEP (diethyl phthtalate) and DCHP (dicyclohexyl phthalate), are being evaluated for endocrine disrupting properties. The lead compounds used in heat stabilizers are classified as toxic for reproduction (category 1A), very toxic to the aquatic environment with long lasting effects (both acute and chronic), and may cause damage to organs (European Parliament and Council, 2008).

1.5. Release and fate

Release of chemicals associated with plastic products may occur in all phases of the life cycle, i.e. during production, use, and end-of-life (Figure 1). The environmental fate of the polymer and of the substances released during the life cycle, including the degradation products, as well as the bioaccumulation potential, will affect the exposure for humans and the environment.

The principal company that has developed these prodegradant additives is EPI Environmental Technologies (Conroe, TX, USA) and their products are trademarked TDPA™ - an acronym for Totally Degradable Plastic Additives. Plastic products manufactured with EPI's TDPA technology progressively degrade to lower and lower molecular weights. They become brittle, disintegrate and are ultimately digested by microorganisms back to the basic elements of carbon dioxide (CO2), water (H2O) and biomass with no harmful residues. TDPAs have been shown not to affect bacteria, fungi or earthworms and they leave no hazardous residues. TDPAs can control the degradation rates of plastics in various degrees, from as short as a few weeks to months or years, at a competitive cost. The prodegradants developed by EPI are also known as degradable and compostable polymer (DCP) additives.

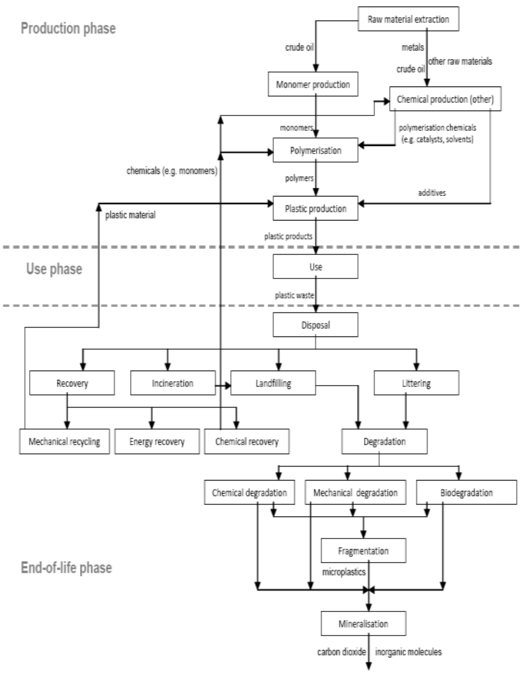

Figure 1.1 The life cycle of a plastic product (excluding energy input and emissions).

1.5.1. Release and release potential

The data of emissions to air and water from production of monomers, polymers and plastic products are very scarce. In EU risk assessment reports available for some of the monomers, there are a few emission data from polymer production. These data show varying emissions between different production sites and different polymers.

Migration is generally favoured if the polymer matrix is permeable; if the size of gaps between polymer molecules is larger than the size of migrant; if the migrant is small, has a similar solubility parameter as the polymer and is volatile; if the temperature is high; and if the surrounding medium is water for water soluble migrants, fat containing for hydrophobic migrant and acidic for metals.

1.5.2. Degradation products

The degradation products formed during degradation will vary depending on polymer type (Ravve, 2000). The type and quantity of degradation products formed may also be influenced by degradation mechanisms, presence of polymerization impurities, and surrounding factors, e.g. temperature and oxygen (La Mantia, 2002; Ravve, 2000).

Polymers capable of depolymerisation by chain scission include polymethyl metacrylate, polytetrafluoroethylene, and polyoxymethylene, which can depolymerise completely into their initial monomers. Also polystyrene, polyesters (e.g. PET and polycarbonate), nylons and polyurethanes can depolymerise to some extent into their monomers. All plastic types emit carbon monoxide and carbon dioxide upon burning.

1.6. Exposure

For workers in the plastics industry the main route of exposure to toxic substances is by inhalation 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.

At the same time, epoxy lining is promoted, and also used in some countries, as a very cost efficient alternative to re-piping in drinking water supply systems (Selvakumar et al., 2002). Epoxy lining means that the epoxy resin is injected and blown through to the piping system to prevent leaks and increase service life (Selvakumar et al., 2002). The most important epoxy resin (>80% of the market) is made from bisphenol A and epichlorohydrin (Gnanou and Fontanille, 2008). Both substances are classified as skin sensitizing, and epichlorohydrin is, in addition, classified as carcinogenic (category 1B). Migration of bisphenol A into food from epoxy lined cans have been shown (e.g. Sajiki et al., 2007; Geens et al., 2010).

Few data on measured environmental concentrations of plastic chemicals exist. In the EU drinking water directive the only parametric (limit) values related to plastic are for vinyl chloride, epichlorohydrin and metals (European Council, 1998). In the Swedish environmental monitoring program some of the plastic chemicals are included or have been screened, e.g. brominated flame retardants, phthalates, bisphenol A, and organotin compounds (Swedish EPA, 2007). Predictions of environmental concentrations (PEC) can be done for selected hazardous chemicals used in plastics.

1.7. 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.

The knowledge of effects from exposure to the mixture of substances that may be released from complexly composed plastic products is very limited. There are some toxicity studies made on different plastic materials. Most of them have been made on rodents exposed, by oral route, to either plastic powder or extracts from the plastic material.

In another study, mudsnails cultivated in PET mineral bottles doubled their reproductive output, due to endocrine disruption, compared to those cultivated in Borosilicate Erlenmeyer flasks (Wagner and Oehlmann, 2009). In a study by Olea (1996), saliva samples collected after treatment with restorative dental filling composites (which are made from thermosetting acrylic composite bis-GMA) contained bisphenol-A and bisphenol-A dimethacrylate. The saliva samples were estrogenic in cell proliferation tests, compared to no estrogenicity in the saliva collected prior to filling.

1.8. 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.

Hazard assessment 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:

1. 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.

2. 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.

Risk assessment 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:

1. Hazard identification
2. Hazard characterization (related term: Dose–response assessment),
3. **Exposure assessment** is the evaluation of the exposure of an organism, (sub)population, or ecosystem to a chemical (and its derivatives).
4. **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 thesis mainly comprises the hazard identification step and parts of the hazard characterisation step.

1.9. Aim of the thesis

The overall aim of this thesis was to study the environmental and health hazards of chemicals in plastic polymers and products from a toxicological perspective. This was achieved by evaluations of toxicity by standardised ecotoxicity tests and by identifying the hazards of chemicals used to produce different plastic polymers. The specific objectives were to:

- determine the acute toxicity of substances leaching from a variety of plastic products, synthetic textiles, and discarded electronic products,
- compare toxicity for different plastic polymer types, product types and components,
- identify which class of toxicants that was causing the toxicity,
- compile and identify the environmental and health hazards of chemicals used in
- plastic polymer production,
- make a hazard ranking of the polymers based on monomer classifications,
- make initial hazard assessments of the polymers,
- identify hazardous substances used in polymer production for which evaluation of risks are needed.

The present study on "Establishing Criteria for Biodegradable Plastics on Environment" sponsored by Central Pollution Control Board (CPCB), New Delhi broadly focuses on assessment of the status of manufacture of Biodegradable Polymers in India with reference to its processing technologies, environmental issues etc. The scope of the work includes the following:

- Inventories/assess the manufacturing status of biodegradable plastics industries manufacturing units in India with reference to processing technologies & environmental issues etc.
- Establish the degradation rate w.r.t change in chemical structure, decrease in mechanical strength, fragmentation and weight loss of polymeric material degradability under laboratory scale composting conditions.
- Evaluate the self-life and its impact on environment.
- Evaluate its effect on food stuffs w.r.t natural colour/additives.

II. METHODS AND APPROACH

2.1. Determination of plastic product leachate toxicity

Since there is such a diversity in the chemical composition of plastic products and basically no knowledge on toxicity of leachates from plastic products, a screening approach with leaching tests, bioassays and toxicity characterisations was chosen. In total 83 plastic products and synthetic textiles were tested. In addition, 68 metal, mixed material or plastic components from discarded electronic products were tested.

2.1.1. Product leaching tests

In order to screen many different products, short term leaching tests were chosen. All products were leached in deionised water during a short term period (1 or 3 days). By using deionised water the comparability is increased and the leachate can be used directly for toxicity testing on any aquatic test species, after the addition of the specific stock solutions required by the test organism. Distilled water is also the required test medium in the EU for testing migration from plastic materials into aqueous food (European Council, 1982).

The Ph of the deionised water was 7.0, which could represent the pH of a lake or river (neither acidic, nor alkaline). There is no general standardised method for testing leaching of plastic products for subsequent toxicity testing. The available methods have been developed for measuring migration levels of chemicals from plastic material and articles that are in contact with food into food simulants (e.g. EN 1186-14:2002), or for measuring migration into artificial sweat or saliva.

Two main methods for leaching were used, one batch leaching method based on CEN (2002) for the characterization of wastes, and one diffusion leaching method. One drawback with the batch leaching method, which involves shaking, is that most VOCs are probably not included in the leachate (Bjerre Hansen and Andersen, 2006). This probable VOC loss may be less with the diffusion leaching method, but can still be considerable (e.g. during preparation of concentration series).

The reasons for increasing the leaching period from 24 h to 3 days was partly because it was convenient; leaching can be initiated on Friday, and toxicity testing (screening, EC50 determination and TIE) can be performed Monday to Friday; and partly to compensate for the possible slower leaching when switching from shaking to leaching by diffusion.

Most products were cut into smaller pieces to enable testing of products with irregular shape and to increase the exposed surface area, which may enhance leaching. Glass laboratory materials were used during leaching and toxicity testing to avoid absorption of hydrophobic substances onto plastic laboratory ware .

Figure 2.1 Plastic product (bib for babies), and synthetic textiles (sporting sweater, stretch pants, and knitted muffler), prior to leaching.

Figure 2.1 Synthetic Textiles (Sporting Sweater, Stretch Pants, And Knitted Muffler), Prior To Leaching.

The highest leaching concentrations for the plastic materials were either 100 or 250 g plastic/L (corresponding to a liquid to solid (L/S) ratio of 10 and 4, respectively), and were lower for the mixed material fraction (50 g/L) and metal fraction (25 g/L) of the electronic products. All products were removed prior to toxicity tests.

III. RESULTS AND DISCUSSION.

- **3.1.2. Toxicity of discarded electronic products**
- Among the discarded electronic products 18 of the 68 leachates showed acute toxicity to Daphnia magna. This represents 26.5%, which is less than for the plastic products and synthetic textiles. These results are, however, not comparable because the highest test concentrations for the tested electronic product

were much lower for metal parts (25 g/L) and the mixed material parts (50 g/L), than for the plastic product and synthetic textiles (100-250 g/L).

- If instead only the 48-h EC50 values ≤25 g/L are considered, a higher share of low EC50s (i.e. more toxic) were found among electronic products, than among the plastic and textile products. However, the test set-up was slightly different, and besides, studies like these should primarily be used for comparing a more similar category of products.

- The eight most toxic leachates had 48-h EC50s ranging from 0.4 to 20 g/L and belonged to the metal or the mixed material category (Table 3). All five tested electronic products contained components that generated at least one toxic leachate. The TIE indicated that cationic metals were the major cause of toxicity for the majority of the leachates, and that hydrophobic organics may have been involved to a lesser extent in a couple of the leachates.

- None of the tested 13 plastic components showed any toxicity at the highest test concentration (100 g/L). Possible explanations for lack of toxicity could be that hard plastics are not particularly acutely toxic under the existing test conditions; that possible content of readily available non-polymeric substances, which are the most likely to leach under the specific test conditions, had already been released during the use phase or were not released in high enough concentrations; and that most plastic pieces were covers and casings which had to be cleaned with a damp cloth to remove dirt prior to leaching, and this may also have removed some possible surface contaminants.
- In other studies plastic fractions from electronic products have been shown to release brominated flame retardants mainly to methanol (20%), and to a lesser extent to distilled water (Kim et al., 2006). The plastic fraction can also be contaminated with heavy metals. For instance, Morf et al. (2007) found average concentrations >1000 mg/kg for Cu, Sb, Sn, Zn, Pb, and Ni in the plastic fraction of various electronic products.
- **3.1.3. Acute toxicity and other toxic effects**
- The laboratory studies in papers I-IV show the acute toxicity of product leachates. This type of toxicity requires exposure to high concentrations of toxicants, or exposure to very acutely toxic toxicants, in order for the adverse effect (e.g. immobility, death) to occur. This means that large amounts of toxicants or very toxic chemicals had to leach from the materials under the short leaching period (1-3 days) in deionised water.
- For many plastic products leaching of chemical substances from the plastic materials is more likely to occur at low concentrations under a prolonged time period, and in many cases also under the influence of degradation. This statement is based on: a) the available data of chemical release from plastic products which are usually measured in the lower concentrations ranges, and b) on the physical structure of the polymer in which the gaps between polymer molecules are often quite small and, thereby, decreases the migration potential.
- Many other toxic effects such as carcinogenicity, mutagenicity, reproductive toxicity, sensitisation and chronic aquatic toxicity, as well as endocrine disruption, are not detected in the acute toxicity tests, but are common for many of the chemicals used for producing plastic polymers, as shown in paper. However, acute toxicity tests can be used for screening purposes to identify toxic products, but should not be used alone to conclude that a certain plastic product is non-toxic.
- **3.2. Hazard ranking and initial assessments**
- In this section only some of the results from paper V are presented and the reader is referred to this paper for further information. The plastic polymers that ranked as the most hazardous ones are made of monomers that are classified as mutagenic and/or carcinogenic. These polymers belong to the polymer families of polyurethanes, polyacrylonitriles, PVC, epoxy resins, and styrenic copolymers (ABS, SAN and HIPS).
- All have a large global annual production, ranging between 1 and 37 million tons. PVC has the largest production of them, accounting for 17% (by weight) of the world plastic demand (India MRG, 2008). All these highly ranked polymers should be prioritised for assessments of risks.
- A considerable number of polymers are made of monomers that have hazard classifications belonging to the two highest of the five hazard levels in the ranking model. These polymers are presented in Table 4. The polymers which are made of level monomers and, in addition, have a large global annual production (1-5 million tons) are phenol formaldehyde resins, unsaturated polyesters, polycarbonate, polymethyl methacrylate, and urea-formaldehyde resins.

IV. PLASTIC WASTE: DRIVERS AND PRESSURES

4.1 . Sources of plastic waste

Plastic waste is a global problem, but with regional variability. This is particularly true of plastic waste in the marine environment, which can travel long distances, carried by currents or transported by wildlife, which ingest or become entangled in plastic.

Waste management varies from country to country. One of the most instrumental EU waste management regulations is the Landfill Directive (1999), which sets targets for the diversion of biodegradable municipal waste from landfill, allowing Member States to choose their own strategies for meeting these targets. However, there are no specific targets for diversion of plastic waste.

4.2 Categories of plastic waste

Categorisation can help us understand plastic waste and identify sources. However, most classifications have a purpose and waste is often categorised with a specific goal in mind. For example, a waste classification designed to support a recycling programme would identify commonly recycled plastics (Barnes et al., 2009). Classification can also depend on policy, for example, Moore et al. (2011) conducted a study on plastic debris in two Californian rivers that categorised pieces as below or above 4.5mm, because Californian law defines rubbish as being 5mm or greater. (Figure.4.3)

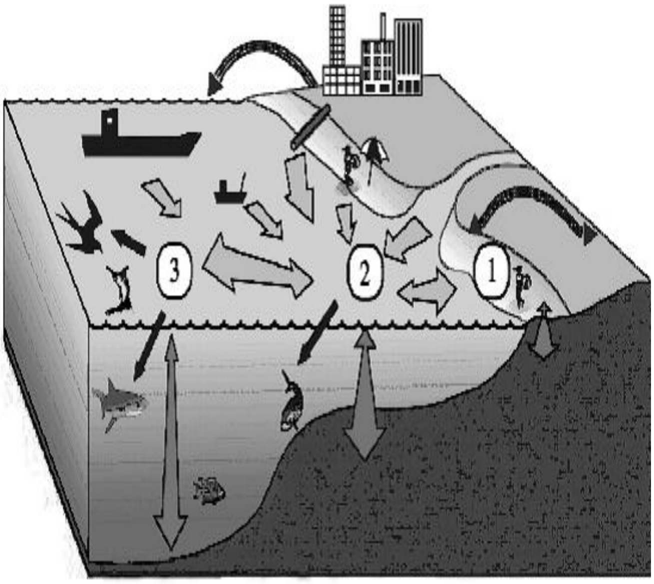

Figure 4.3 Main sources and movement pathways for plastic in the marine environment. (from UNEP Year Book, Kershaw et al., 2011)

V. STATE OF PLASTIC WASTE

As production and use of plastic has increased over the years, a large amount of plastic waste has accumulated in the environment. As a durable material, it is also persistent. Recycling and recovery rates may be improving, but the actual amount of plastic waste produced remains roughly the same and adds to existing waste.

There is little information on the amounts, rates, fate or impacts of plastic waste on land, whereas there has been a major effort to quantify impacts on shorelines and sea (Barnes et al., 2009). If it is not recycled or recovered, most plastic waste is disposed of in landfill sites where, although not visible, it may still come to the surface as ‘debris’. In addition, the conditions within landfill may cause the chemicals contained within plastic to become more readily available to the environment. This is a particular concern in developing countries where landfill management is not as closely monitored as in the EU.

5.2 The marine surface - monitoring plastic waste floating at sea

Surveys at sea are more costly and challenging than beach surveys and can only assess standing (or floating) stocks rather than accumulation rates, because it is impossible to perform a complete clean-up. Amounts of floating debris can be estimated either by direct observation or by net trawls.

In general, net-based surveys tend to be less subjective. Most research has been done using Neuston or Manta trawl nets, which have a small mesh (usually 0.3mm, and small net opening and thus focus on microplastics). Manta trawls have been used to sample and characterise the large gyre systems in the oceans with elevated amounts of clustered marine litter (Pichel et al., 2007). One of the most well known research programmes that use this method is the Algalita Centre, which regularly monitors the North Pacific Subtropical Gyre (see Figure 7). In 1999, they reported just under 335,000 items of plastic per km2, weighing 5.1 kg per km2 (Moore et al., 2001).

VI. CONCLUSION

In developing state and local policy related to the environmentally beneficial uses of degradable plastics, it is to consider the implications of any policy or program on the affected waste diversion and disposal systems. Because improvement in one area of a system can sometimes adversely affect another part of the system. In Indian context, considering the local environment, social fabric, culture and habits of public indiscriminate system of plastics waste management wide spread littering etc, introduction of biodegradable plastics, packaging products would further add to the apathy of plastic waste disposal by adding another dimension / family of plastics.

Degradation from biological sources is called biodegradation and may be defined as compostable, which specifies that plastic is not only biodegrades completely but is also consumed in 180 days, while being in a proper compost environment as per ASTM D-6400 or IS/ISO: 17088: 2008 Standards, which defines the criteria for biodegradable plastics under compostable conditions.

The compostable bags meeting ASTM D-5338 or IS/ISO : 17088:2008 standards will degrade in a compost environment may not break down on ambient environment. Therefore, it can be concluded that biodegradable or compostable plastics may not be a better option.Designing hydrophobic polyolefin plastics to be degradable without ensuring that degraded fragments are completely assimilated by microbial population in the disposal system, in a short time period, poses more harm to the environment, hence it is recommended that biodegradable plastics can be used for short life applications.

Worldwide the law/ Legislations exist for use of biodegradable plastics in short lived applications particularly in food/ perishable goods packaging etc. The high cost of biodegradable plastics, which aremeeting criteria of compostable specifications as per ASTM D-6400 orIS/ISO 17088:2008, is the major concern to introduce in common “grocery/ carry bags” applications.

- Substances causing acute toxicity to Daphnia magna leached from one third of all 83 tested plastic products and synthetic textiles even during the short term (1-3 d) leaching period in deionised water.
- The toxic leachates came mainly from products that were soft to semi-soft, i.e. plasticised PVC (11/13) and polyurethane (3/4), and from epoxy products (5/5), and from synthetic textiles made from various plastic fibres.
- Only one each of the 13 polyethylene, 10 polyester and 9 polypropylene leachates were acutely toxic.
- A considerable number of leachates from products intended for children (5/13) were toxic.
- None of the 12 leachates from articles for food or drinking water contact were acutely toxic.
- The toxic leachates from discarded electronic products came from the mixed material or the metal fraction, but none came from the pure plastic fraction.

With the introduction of bio-degradable plastic bags in the waste system, it would be difficult to comply with existing regulations i.e. “Plastics Manufacture and Usage Rules, 1999, as amended in 2003” which is meant for manufacturing and usage of conventional plastic bags, therefore, it needs an amendment. There is also need to establish or create testing facilities for testing of Biodegradable plastics as per BIS Standard IS/ISO: 17088:2008.

REFERENCES

[1]. Aliani, S., A. Griffa & A. Molcard. (2003). *Floating debris in the Ligurian Sea*, northwestern Mediterranean. Marine Pollution Bulletin 46: 1142-1149.
[2]. Allsopp, M., Walters, A., Santillo, D. & Johnston, P. (2006) *Plastic Debris in the World’s Oceans*. Greenpeace International. Downloadable from http://oceans.greenpeace.org/en/documents-reports/plastic_ocean_report
[3]. Aloy, A.B., Vallejo, B.M. & Juinio-Meñez, M.A. (2011) *Increased plastic litter cover affects the foraging activity of the sandy intertidal gastropod Nassarius pullus*. Marine Pollution Bulletin 62:1772-1779.
[4]. Andrady, A.L. (2011) *Microplastics in the marine environment*. Marine Pollution Bulletin 62:1596-1605.
[5]. Arthur, C., Baker, J. & Bamford, H. (2009) *Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*. Sept 9-11, 2008. National Oceanic and Atmospheric Administration Technical Memorandum NOS-OR&R-30.
[6]. Auman, H.J., Ludwig, J.P., Giesy, J.P. & Colborn, T. (1997) *Plastic ingestion* by Laysan Albaross chicks on Sand Island, Midway Atoll, in 1994 and 1995. In G.Robinson & R. Gales (eds.) Albatross Biology and Conservation. Surrey Beatty & Sons, Chipping Norton. Chapter 20 pp 239-244.
[7]. Ashton, K., Holmes, I. & Turner, A. (2010) *Association of metals with plastic production pellets in the marine environment*. Marine Pollution Bulletin, 60(11):2050-2055
[8]. Balance, A., P. Ryan, and J.K. Turpie. (2000) *How much is a clean beach worth?* The impact of litter on beach users in the Cape Peninsula, South Africa. South African Journal of Science 96: 210-213.
[9]. Barnay, A., Degre, E., Emmerson, R. et al. (2010) *Evaluation of the OSPAR system of Ecological Quality Objectives for the North Sea* . OSPAR Commission Biodiversity Series.
[10]. Barnes, D.K.A & Milner, P. (2005) *Drifting plastic and its consequences for sessile organism dispersal in the Atlantic Ocean*. Marine Biology 146:815-825.

[11]. Barnes, D.K.A., Galgani, F., *Thompson, R.C. & Barlaz, M. (2009) Accumulation and fragmentation of plastic debris in global environments.* Philosophical Transactions of the Royal Society B. 364:1985-1998.

[12]. Ben-Jonathan, N., Hugo, E.R & Brandebourg, T.D. (2009). *Effects of bisphenol A on adipokine release from human adipose tissue*: Implications for the metabolic syndrome. Molecular and Cellular Endocrinol 304(1-2): 49-54.

[13]. Boerger, C.M., Lattin, G.L., Moore, S.L. & Moore, C.J. (2010) *Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre.* Marine Pollution Bulletin 60:2275-2278.

[14]. Bowmer, T. & Kershaw, P. (2010) *Proceedings of the GESAMP International Workshop on Microplastic particles as a vector in transporting persistent*, bio-accumulating and toxic substances in the ocean. GESAMP Reports & Studies No. 8

[15]. Browne, M.A., Galloway, T. & Thompson, R. (2007) *Microplastic – An emerging contaminant of potential concern?* Integrated Environmental Assessment and Management 3(4):559-566.

[16]. Browne, M.A., Dissanayake, A., Galloway, T.S. et al. (2008) *Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel, Mytilus edulis (L.)* Environmental Science & Technology 42(13): 5026-5031.