Brominated Flame Retardants

Spreading the Fire

A Report on the Recycling of Brominated Flame Retardant Contaminated Plastic

By
Toxics Link

Toxics Link
for a toxics-free world

About Toxics Link

Toxics Link emerged from a need to establish a mechanism for disseminating credible information about toxics in India, and for raising the level of the debate on these issues. The goal was to develop an information exchange and support organization that would use research and advocacy in strengthening campaigns against toxic pollution, help push industries towards cleaner production and link groups working on toxics and waste issues.

Toxics Link has unique expertise in the areas of hazardous, medical and municipal wastes, as well as in specific issues such as the international waste trade, and the emerging issues of pesticides and POPs. It has implemented various best practice models based on pilot projects in some of these areas. It is responding to demands upon it to share the experience of these projects, upscale some of them, and to apply past experience to larger and more significant campaigns.

Toxics Link
for a toxics-free world

Toxics Link
H-2, Jungpura Extension
New Delhi – 110014
Phone: +91-(11)-24328006, 24320711
Fax: +91-(11)-24321747
Email: info@toxicslink.org
http://www.toxicslink.org

Research Team: Satish Sinha, Priti Mahesh, Vinod Sharma

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Executive Summary

Around 50 million of E-waste is generated globally. This raises huge concern, not just because of the enormous quantity but also because of the presence of toxic materials. Use of Brominated flame retardant is one such concern. Plastic is one of the dominant materials used in EEE and around 12% of this plastic used in EEE contains flame-retardants, mainly brominated flame-retardants.

Brominated Flame-retardants are known to leak from the products into our air, dust, water, and environment and eventually enter our food and bodies. Human exposure to BFRs may occur during production, transportation and industrial processes, or through the use of BFR-containing products. Over the lifetime of a product PBDEs are slowly released - with tiny dust particles that chip off the surface of computer equipment. At home and in the office we may be continuously inhaling small quantities of PBDEs, which tend to linger in the body and accumulate to higher levels after long-term exposure. But the real toxic hit happens during the recycling process.

Studies globally have indicated the occupational and environmental risk associated with use of BFRs, specially during recycling of the BFR contaminated plastics. In some earlier studies in US, China, Sweden, and Norway, workers at electronics recycling plants have been shown to elevated serum levels of polybrominated diphenyl ethers (PBDEs) compared to the general population. The concern in India is heightened because most of this plastic from EEE (referred in this study as E-plastic) is recycled by the unorganized sector or informal sector. There has been no attempt in India to document such process or the resulting exposure.

Another major concern is recycling of this contaminated plastic to produce new products, leading to the unintended presence of BFR in non-EEE products, where there is no requirement for flame-retardants. This may lead to wider exposure to this toxic material.

The present study was undertaken to investigate the issue of cross contamination and do a preliminary research on the presence of BFRs in recycled plastics. The study also aimed at documenting the material flow of plastics from computers in the informal sector and to assess the possibility of exposure of BFRs for Indian workers in recycling units/plants or reusing manufactories

Findings of the report are:

- The plastic recycling in the informal sector in Delhi is widely spread out. Some of the hotspots include Bawana, Narela, Mundka and Bhopura.
- There is no occupational and environmental safety norms observed during the recycling processes in the unorganized sector.
- Recycling of BFR contaminated plastics may lead to BFR exposure due to inhalation of dust released during processes.
- Use of high temperature during pellet making process may lead to formation of brominated dibenzofurans, which are known carcinogenic.

- There are no processes used to remove BFR during plastic recycling in the informal sector. There is a risk of cross contamination as these recycled plastic pellets are used to manufacture new products.
- Out of 10 recycled plastic pellets tested under this study, 5 of them contained Brominated flame-retardants.
- All three plastic resins included in this test, namely HIPS, ABS and PC, were found to be contaminated with PBDEs
- Different congeners of PBDE were detected in all of these five samples, namely Hepta, Octo, Nona and Deca.
- The concentrations of Deca-PBDE detected in 5 samples ranged from 140 mg/kg to 39602 mg/kg

Recommendations:

The finding of the study demonstrates the presence of brominated flame-retardants in the recycled plastic. The sample size in this study being limited, this warrants for a detailed study the issue of cross contamination.

There is also a need to look closely at the recycling practices in the country.

1. Introduction

1.1. Background

We are all aware of flame-retardants are around us, they are present in many products that we use at our workplaces or in our homes. Fire resistant chemicals, known as "flame retardants", are added by manufacturers to meet fire safety norms and to slow down the spread of fires or to prevent them from occurring. These chemicals have been increasingly added greater degrees since the 1970s to consumer products such as electronics, upholstered furniture and transport vehicles. Unfortunately many of these flame-retardants do not remain contained within the product. Instead, they leak slowly from the products into our air, dust, water, and environment and eventually enter our food and bodies. The subsets of these flame-retardants, called "Brominated Flame Retardants" (BFRs), are now the subject of intense scrutiny and various studies undertaken. There is enough evidence available to predict that they are likely to persist in our environment, bio accumulate in the food chain and in our bodies, and cause adverse health problems. In the past decade, scientists have detected BFRs both in human and wildlife tissues as well as in house dust, sediments, sewage sludge, air, soil, and water samples.

It is possible that entire life cycle of BFRs is the prime factor responsible for their distribution into the environment. Industrial, as well as manufacturing facilities that produce BFRs and incorporate BFRs into consumer products release these chemicals during polymer formulation, processing, or manufacturing practices. Studies have suggested that BFRs are released during their usage as well. Finally, disposal of products, including combustion, recycling of waste products and leaching from landfills, is the final route of entry for BFRs into the environment.

The impact on the health of humans of some BFRs like PBDE are fueling debate around the use of these chemicals in consumer products, especially electronics and an urgent need for the safe recycling of BFR contaminated plastics is perceived.

1.2. E-Waste

In the last two decades rapid changes in the information and communication technology and the increasing demand for consumer electrical and electronic equipments have led to a significant growth of the electrical and electronic manufacturing industry worldwide. Although the benefits of ICT and EEE are well known and recognized, little is known about the end of-life management of such devices.

What constitute E-Waste? E-Waste consists of discarded or end of life computers, mobile phones, televisions and many small and large household and office equipments. The waste generated by electrical and electronics equipment or E-Waste has seen exponential growth in recent times and currently around 42 million tones are generated globally, per annum, and is set to go up to 53 million by 2012, thus growing at a CAGR of 6 percent. The rapid rate of growth is an indication that it is the fastest growing segment of the municipal solid waste stream.

The toxic materials present in E-Waste place human health at considerable risk and are potentially dangerous for the environment. E-Waste contains several persistent, bio-accumulative and toxic substances (PBT) including heavy metals such as lead, nickel, chromium, mercury and persistent organic pollutants such as polychlorinated biphenyls and Brominated Fame-Retardants. If not recycled using proper methods this waste, releases toxins into the air, water and soil and thus the health of humans and the safety of the environment..

In India and other developing countries, a huge surge in consumerism has been noticed, especially in the last decade or so, due to rapid economic growth. This has led to greater consumption as well as increase in the replacement market, leading directly to the growing pile of waste. More than 4 million tonnes of E-Waste is generated annually in India today and it is expected to double to 8 million MT by 2012. Unfortunately this is mostly processed and recycled in the informal sector using crude waste management techniques, leading to health and hazardous environmental issues that need attention, urgently.

Another issue that is linked is dumping of E-waste in India through illegal imports. This dumping of E-Waste contributes to the deterioration of the environment as well as the health of human beings in the downstream end of the electrical and electronic equipment supply. Developing countries like India lack an infrastructure for sound hazardous waste management including recycling, or effective regulatory frameworks for hazardous chemicals. Illegal dumping and trade in E-Waste raises an equity issue, is it fair that developing countries should be receiving a disproportionate burden of a global problem when they are not equipped to deal with it?

1.3. The Present Context

The use of BFRs in consumer products such as electronics poses an exposure risk, particularly at the time of their disposal. Unauthorized recycling operations in developing countries like India further heighten the risks, as there are no environmental or occupational safety measures taken into account. In India, large quantities of electronic waste from around the globe are dismantled for recycling in small, usually 'back-yard' units. The methods used to dismantle the electronic equipment are primitive, with little or no personal safety measures taken or attempts made to control exposure to the chemicals present in the waste. Therefore, it is important to ascertain the recycling impacts of these operations, both in terms of occupational hazard as well as constituting a threat to human health and the environment.

2. Objective and Methodology

Although there have been some studies undertaken globally to assess BFR concentrations in recycling workers, in India, very little has been done to ascertain the vulnerability of the informal recycling sector to hazards presented by BFRs. Also there has been no attempt to assess the issue of cross contamination, i.e. the BFR presence in the recycled plastic pellets and the products manufactured from them. BFR contaminated plastic recycling becomes a very crucial issue, with India being a major recycling centre, both for domestic as well as for dumped E-Waste.

The aim of this study is to:

- To document the flow of plastics from computers in the informal sector and to assess the possibility of exposure of BFRs for Indian workers in recycling units/plants or reusing manufactories and the impact of those chemicals on the environment.
- To investigate the cross contamination issue-a preliminary research on the presence of BFRs in recycled plastics.

The study employs various methods like reviewing of existing literature, unstructured interviews, exploratory surveys and photo documentation to assess the problem and the way BFR contaminated plastic was recycled in Delhi and its adjoining areas. Experiences from earlier studies of Toxics Link in Delhi were used to plan the study.

The research was carried out in phases-

- Review of the existing literature
- Exploratory visits and unstructured interviews with the informal recyclers
- Observations regarding the health and environmental impacts
- Testing of Recycled Plastic Pellets for BFRs

Literature review: An extensive literature review was undertaken to collect information on BFR usage in EEE and its health impacts.

Exploratory survey: Interviews were undertaken with traders, dismantlers and recyclers to enable us to understand the market flow and their trade practices. Informal discussions were carried out and emerging trails were followed to investigate such activities. The recycling units were surveyed to assess the environmental and occupational health impacts.

Observation: Numerous visits were made to the plastic recycling units in and around Delhi to observe the practices and their related health and environmental impacts.

Testing: The plastic pellet samples were collected from the informal recycling units in Delhi and sent to an accredited laboratory for testing for selected BFRs. The samples were tested for the commonly used BFRs for EEE.

3. Brominated Flame Retardants

3.1. BFRs and its Uses

We know now that chemical flame-retardants are added to many materials and products prevent or suppress ignition or to limit the spread of fire once ignition occurs. They have been credited with saving many lives and preventing injuries and loss of property as a result of mandated or voluntary use. There are hundreds of flame-retardants available today, and more are being developed for specific uses. A wide variety of chemicals and chemicals belonging to the same category are employed as flame-retardants, including inorganic chemicals based on the elements phosphorus, aluminum, magnesium, zinc, and antimony, and organic chemicals based on bromine and/or chlorine (organohalogens), phosphorus (organophosphates), and nitrogen. The products that contain bromine comprise a significant portion of the flame retardant market due entirely to this element's effectiveness at suppressing ignition and stopping the spread of flame, and at a relatively low cost. Brominated Flame Retardants (BFRs) belong to a family of 75 chemical substances with different properties, characteristics, and performance levels. Bromine, present in nature is the only common element that is shared by all of them.

Worldwide, approximately 5,000,000 metric tons of bromine is produced each year [Bromine Science and Environmental Forum (BSEF) 2000]. As of 2000, BFRs accounted for 38% of the global demand share of bromine, a sharp increase compared with 8% in 1975. More than 200,000 metric tons of BFRs are produced each year (BSEF 2000). The production of BFRs has increased dramatically over the past 20 years, with the largest relative increase recorded at this time being in Asia. As of 2001, Asia (consumed) an estimated 56% of the total market demand, and the Americas and Europe consumed 29% and 15%, respectively (BSEF 2001).

BFRs belong to five major categories: brominated bisphenols, diphenyl ethers, cyclododecanes, phenols, and phthalic acid derivatives. The first three categories represent the highest production volumes. In fact, five BFRs constitute the overwhelming majority of BFR production at this time. The five major BFRs are tetrabromobisphenol A (TBBPA), hexabromocyclododecane (HBCD), and three commercial mixtures of polybrominated diphenyl ethers (PBDEs), or biphenyl oxides, which are known as decabromodiphenyl ether (DBDE), octabromodiphenyl ether (OBDE), and pentabromodiphenyl ether (pentaBDE). HBCD, TBBPA, and PBDEs are used as additive or reactive components in a variety of polymers, such as polystyrene foams, high-impact polystyrene, and epoxy resins [World Health Organization (WHO) 1994]. These polymers are then used in the production of a variety of consumer products, including computers, electronics and electrical equipment, televisions, textiles, foam furniture, insulating foams, and other building materials.

It has been observed that there are remarkable differences region wise, in the consumption patterns of the five major BFRs For example, of the 117,950 tons of BFRs consumed by Asia in 2001, approximately 76% was TBBPA, 21% PBDEs, and 3% HBCD (BSEF 2001).As opposed to the 53,900 tons used by the Americas, 34% was TBBPA, 61% PBDEs, and 5% HBCD. The congener-specific breakdown of the PBDEs differs widely from region to region. Globally the most widely used PBDE is DBDE, used in the same degree in America and Asia. PentaBDE is essentially used only in America, whereas OBDE remains a minor product worldwide. Some of these differences may have occurred due to the voluntary ban on PentaBDE in Europe (formalized as of July 2003), which was then followed by a European Union directive restricting the use of PentaBDE and OBDE in electrical and electronic equipment by 1 July 2006.

3.2. BFRs in EEE

BFRs are added to plastics used in Electrical and Electronic Equipment (EEE) to slow down or prevent the ignition of fire. Approximately 12% of the plastics used in EEE contain flame-retardants, in most cases comprising Brominated Flame-Retardants (BFRs). Since the 1970s, the electronics industry has been one of the largest consumers of PBDEs, relying on this class of chemicals to meet fire safety standards. About 40% of PBDEs are used in the outer casings of computers, printers and televisions and by far the largest volume of the PBDE mixture used as a flame retardant has been Deca-BDE. With the emergence of the new processors running faster, EEE are more liable to catch fire, while taking into account the augmentation of the heat triggered in these materials. Flame Retardants, when used in EEE, may save lives and reduce property damage by preventing the spread of flame and fire. For these reasons BFRs are mainly found in EEE, used either as additives and are not covalently bound to the structure so they can move into the environment. Hence when these products reach the end of their useful lives, some disposal or recycling operations can release the bromine in other hazardous forms into the environment, these chemicals can then turn into brominated dioxins when electronic waste, or other products containing these chemicals, are incinerated or combusted. Another risk factor is that the BFRs remain in the plastics and the plastic products made out of these recycled plastics though it may not have been originally intended.

The major applications of BFRs in EEE are brown goods, office equipment, and printing circuit boards.

The main plastics, used in EEE, are:
- High Impact Polystyrene (HIPS) in brown goods
- Styrene Copolymers (ABS) in data processing & office equipment
- Epoxy resins in printed circuit boards.

The major BFRs associated with these plastics are Decabromodiphenyl ether (DecaBDE) in brown goods, Tetrabromobisphenol-A (TBBPA) in data processing & office equipment and TBBPA in printed circuit boards. The more frequently used polymer for brown goods is HIPS (High Impact Polystyrene). HIPS is generally associated with the BFR decabromodiphenyl ether (DECA). Housing of office equipment is generally associated with the BFR's tetrabromobisphenolA (TBBA) and octabromodiphenyl ether (OCTA) or brominated epoxy oligomers (produced from TBBA).

BFRs are considered to be highly efficient as FRs and economically advantageous both regarding production and consumption, resulting in no alteration of physical properties of electrical and electronic equipment.

3.3. BFRs- Hazard

The concerns about Brominated Flame-Retardants emerged in the 1970s when polybrominated biphenyls (PBBs) were discovered in the feed for dairy cattle, livestock, and poultry in Michigan, USA. Widespread PBB contamination of milk, meat, and eggs in the region resulted in the exposure of over 9 million humans to the toxicant. The U.S. government acted quickly, suspending the use of PBB flame-retardants in 1979.

It is becoming increasingly evident that BFRs are similar to PBBs and another category of banned persistent, bio-accumulative toxicants—polychlorinated biphenyls (PCBs). Controlled studies in laboratory animals show that some BFRs disrupt thyroid function, causing hyperactivity and problems with learning and memory. The impacts of BFRs on the humans who have been exposed to them have not been studied yet; however, the results in animals are likely to predict impacts on developing humans, e.g. fetuses and children. The scientific evidence available on PBDEs to date indicates that these chemicals share many common traits with PCBs, including animal studies linking them to immune suppression, cancer, endocrine disruption and neurobehavioral and developmental effects. PBDE levels now present in some humans are close to the levels shown in animals to have negative effects. A recent study also found a significant decrease in the fecund ability associated with PBDE exposure in women. It is not yet fully understood how humans are exposed to the BFRs (especially PBDEs), but ingestion (food and dust) and inhalation seem to be the prime routes of exposure.

Figure 1: BFR Contaminated Plastic in an Informal E-Waste Recycling Unit

Brominated Flame-Retardants, especially PBDEs, are persistent in the environment and are liable to contaminate the food chain, animals and people. The capacity of PBDEs to bio-accmulate in fatty tissue and bio magnify up the food chain, in combination with their persistence and toxicity make this class of chemicals of high concern to the environment and human health. Several BFRs, including certain PBDEs and HBCD, which are known for their toxic properties, are highly resistant to degradation in the environment. Some are now widespread and regarded as environmental pollutants, with higher levels generally being found in the atmosphere and rivers close to urban and industrialized areas. Rapidly increasing levels have been measured in sediments, marine animals and humans, indicating a significant potential for damage to ecological and human health.

The chemical structures of BFRs are very stable—they don't break down easily in the environment where they attach to particles and accumulate in mediums such as dust and sediments. BFRs are also light enough to be transported long distances through the atmosphere. In the past decade, BFRs have been detected in sediments, sewage sludge, air, soil and water samples in the U.S., Canada, the Arctic, northern Europe, Taiwan and Japan. Similar to PCBs, BFR concentrations have been found to increase upwards in the food chain, indicating that the body readily absorbs these chemicals where they accumulate in the fatty tissues. Rapidly rising PBDE levels have been documented in living tissue, from humans, mammals and other wildlife.

Studies that have been carried out in Sweden examined human milk samples collected over a period of about thirty years showed that the concentrations of some BFRs, PBDEs have increased exponentially with their concentration doubling approximately every 5 years during that period (Meironyte et al. 1999, Noren and Meironyte 2000). Brown et al 2004, observed that this trend coincided with the increased production and use of BFRs. This trend peaked in 1997, after which levels began to decline in Sweden. Whether this was because of the voluntary ban on the production and the use of Penta congeners in Europe, which came into force in the early to mid 1990s, is not clear. In contrast, limited data from North America indicate that the concentrations of PBDEs are much higher there than those ever reached in Europe.

BFR release from EEE has also been a cause for concern. There have been studies to check the dust from computers to assess BFR release and also to check release during the recycling process. Indoor air in an electronics goods recycling plant in Sweden was found to be contaminated with higher concentrations of PBDEs compared to other workplace environments. BFRs especially PBDEs have the potential to form brominated dioxins and furans during the processing of waste plastics containing FRs (Schlummer et al., 2006)

3.4. Legal Framework

In recognition of the concerns related to the use of Brominated Flame-Retardants, there have been some initiatives taken in certain parts of the globe to regulate and restrict its usage. The most important one among them being the European Union RoHS Directive. The RoHS Directive (the Restriction of Hazardous Substances Directive) bans the placing of new electrical and electronic equipment containing more than agreed levels of six substances - lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants on the EU market. The EU has banned the use of PBB and Penta and Octa BDE in new E& E equipment after July 2006. The law in EU also mandates separation of BFR containing plastics, prior to recovery and recycling. Following the RoHS Directive China and Korea have also implemented similar regulations.

The Japanese PRTR Law promotes industrial voluntary improvements in the management of specific chemical substances and requires businesses handling such substances to report the release to the environment and to provide technical information on the properties and handling of such substances. Deca-BDE is mentioned in the PRTR law, which means that annual reports have to be produced on volumes imported, volumes used and quantities released in the environment on Deca-BDE.

In US, production and use of Penta-BDE and Octa-BDE was voluntarily phased out by its producers in 2004 in cooperation with the US EPA. State legislations formalizing this phase-out have been adopted in California, Hawaii, Illinois, Maine, Maryland, Michigan, New York, Oregon and Rhode Island. There is no legislation restricting the use of TBBPA in the US. No federal action has been taken to limit or restrict the use of Deca-BDE; however a couple of states like Maine and Washington prohibit some select uses.

In June 2005, the Australian Ministry for Health and Ageing declared TBBPA and Deca-BDE "Priority Existing Chemicals (PECs)". As PECs, each of these Brominated Flame Retardants will be subject in the near future, to an assessment of their potential effects on human health and the environment, which will be conducted by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS). The Australian authorities are currently compiling information on quantities and use of these substances from importers and producers.

Eco labels like the Nordic Swan, Blue Angel and European White flower also look at BFR content in products.

Table 1: Regulations on BFRs

Countries	TBBPA	Deca- BDE	Penta – BDE	Octa- BDE
USA	No restriction	No restriction	Production- Voluntary phase out (state level legislations)	Production- Voluntary phase out (state level legislations)
Japan		PRTR Law*		
EU		Banned under RoHS#		
India	**No regulation or limits**			

*Law on Pollutant Release and Transfer Register
Restriction of Hazardous Substances Directive

3.5. Alternatives to Halogenated Flame Retardants

It is becoming increasingly evident that some halogenated flame retardants are persistent in the environment, bio-accumulative in wildlife and humans and are potentially toxic; there have been attempts to opt for safer alternatives. Initial analyses suggest that safer chemical substitutes are available. For example, a report commissioned by the German government determined that the flame-retardants aluminum trihydroxide, ammonium polyphosphates and red phosphorus are likely to cause fewer problems in the environment. Research results in Europe have revealed that a wide range of non-halogen alternatives in computer casings and printed circuit boards can be substituted for Brominated Flame Retardants and some of the more progressive companies are already making the switch. The most widely marketed and available non-halogenated alternatives are based on phosphorous compounds such as phosphonates, phosphinates and phosphourous esters.

Extensive research is on-going into finding better alternatives. Some of the researches include

- Nano-composites
- Polymer Siloxanes

4. Plastic Recycling in Delhi

Plastic is a primary material used in Computers and other in EEEs. In a standard PC, the plastic content weighs around 22%. The plastics used consist of the following resin types:

* Acrylonitrile Butadiene Styrene (ABS)
* Polyphenylene Oxide (PPO)
* High Impact Polystyrene (HIPS)
* Polycarbonate (PC)
* Polyvinylchloride (PVC).

A study was conducted for this project, we focused mainly on three kinds of plastic resin, namely ABS, PC and HIPS These plastics are used mainly for cables, printed circuit boards and housing. BFRs are usually added to these plastics to make them fire resistant.

To begin with this study required surveys which were conducted in some of the known E-Waste recycling areas in Delhi. Our E-Plastic journey began in **Shastri Park, Seelampur and Mustafabad,** which are the prime areas for computer scrap trading and pre-processing. Discarded computers and their peripherals from consumers, individual as well as businesses, reach here through various levels of trading. Some of the lanes and by lanes in these areas are dotted with small scrap shops where computers, their peripherals and components are regularly dismantled and pre processed.

In these shops, young boys between the ages of 14-20 dismantle and segregate computer parts depending on the material used and its components. For example, a CPU is opened, using mainly hand tools, and plastic casings, wires, circuit boards, hard disks, fans etc are separated and then sold for further processing. Most plastic parts of EEE mention the resins used and are then segregated accordingly. If not specified, the workers have their own way of recognizing them, mainly through different sounds that emanate from them while they are being beaten. However in certain cases where it might be difficult to separate resins, these are sold as mixed plastic.

The plastics from computer parts like CPUs and Monitors are separated in most of these units and are sold by weight and fetch different prices, depending on the resin content. For example, ABS is sold at a rate of between 33 to 36 rupees per kg, whereas HIPS would fetch between 20-25 rupees per kg. If these resins are sold without being segregated, they fetch lower rates (Table 1: Column 2). Plastic prices also depend on whether they contain flame retardant or not. Flame retardant plastic resins sell at around 3-4 rupees cheaper than the ones without it. Keyboards are normally sold per piece, for around Rs.15 per unit, and the mouse units are sold at Rs. 18-20 per kg.

Table 2 Economics of Recycled Plastic

Resin Type	Price (waste)	Pellet prices
ABS	Rs.33-36/kg	Rs. 36-70/kg
HIPS	Rs. 20-25/kg	Rs. 25-37/kg
Hard	Rs. 5-17/kg	Rs. 10-22/kg
Mix	Rs. 15-22/kg	-
Norell	Rs. 15-22/kg	-
PVT	Rs. 11/kg	Rs. 20/kg

- A mix of ABS & HIPS waste is sold at Rs.23-25/ per kg.
- PC waste is sold at the rate of Rs.12-17 /-per kg.
- The traders sell waste with a margin of Rs. 4-5 per kg including labor, godown charges & transport etc.
- There is a difference of Rs.3-4/- per kg in the cost of plain plastic and FR contaminated plastic waste. FR is cheaper than the plain one.

Traders, located mainly in Shastri Park and Mustafabad, pick up waste from these shops. These traders have godowns or storage space in the above mentioned areas for storing these plastic materials. These traders sell it for a further margin of around 4-5 rupees per kg.

4.1. Plastic Recycling Areas of Delhi

Figure 2: Plastic Recycling hotspots in Delhi

These plastic parts are picked up by units, which are involved in grinding and pellet making processes from these go downs. These facilities are spread over various parts of the city, mainly in **Mundka, Bawana, Bhopura and Narela**. A couple of units were found in Karawal Nagar, Pooth Kalan Gaon and Kamruddin Nagar. Most of these units deal with all kinds of plastic, including ABS, HIPS and PVC and these plastics could be sourced from different industries, apart from WEEE. The bought plastics are either already segregated or can be sold mixed. The non-segregated plastics are segregated as they then get a better price for certain resins. The workers have different ways of recognizing resins, for example, by chemical testing, sound, and smell or through burning.

Once the plastic scrap is segregated it is manually fed into the shredder/grinder and it emerges shredded into flakes, ground or cut, reducing the size of the plastic parts. At the time hard plastic components containing Brominated Flame Retardants are shredded, workers are at a risk of being exposed to the dust contained in these chemicals. These workers in shredding areas are not provided with any protective gear, they work with only pieces of cloth covering their mouth and nose to prevent direct inhalation of dust.

After the grinding process is completed the plastic is segregated into FR plastic and Non FR plastic using salt water in sink-float tanks. The plastic pieces contaminated by FR settle at the bottom of the container containing saline water and are collected separately. These ground plastic pieces are then dried and packed up and are bought by pellet manufacturing units.

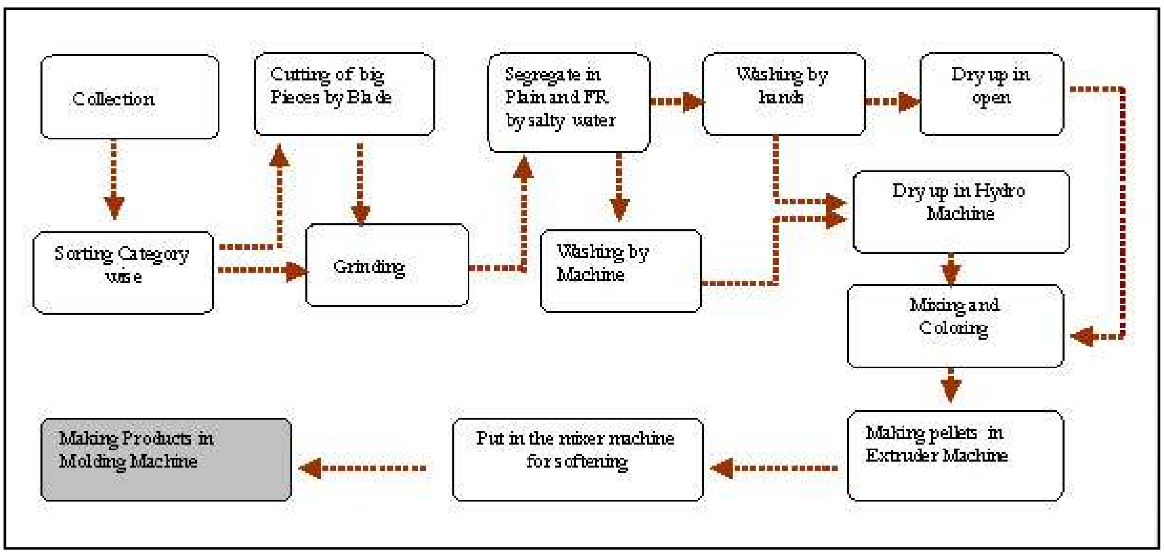

Figure 3: Plastic Recycling Process in the Informal Sector

The pellet making units and the grinding units are usually situated in the same areas so it is convenient for them to be washed clean of the dirt adhering to them. The plastic granules are then dried in a dryer or in the open, after which they treated in a mixture machine. The friction and the heat generated, in the mixture machine makes the material soft and pliable for further processing.

The recycling of plastics involves extrusion to make new products once the preliminary processing has taken place. Extrusion is an important part of polymer processing. At this stage the input material is fed in through a shaft and is caused to melt by passing through a heated chamber. The use of heat in the extrusion of plastics containing Brominated Flame-Retardants can cause the formation of Brominated furans and dioxins. It was noticed that no safety norms were observed in most of these pellet making units.

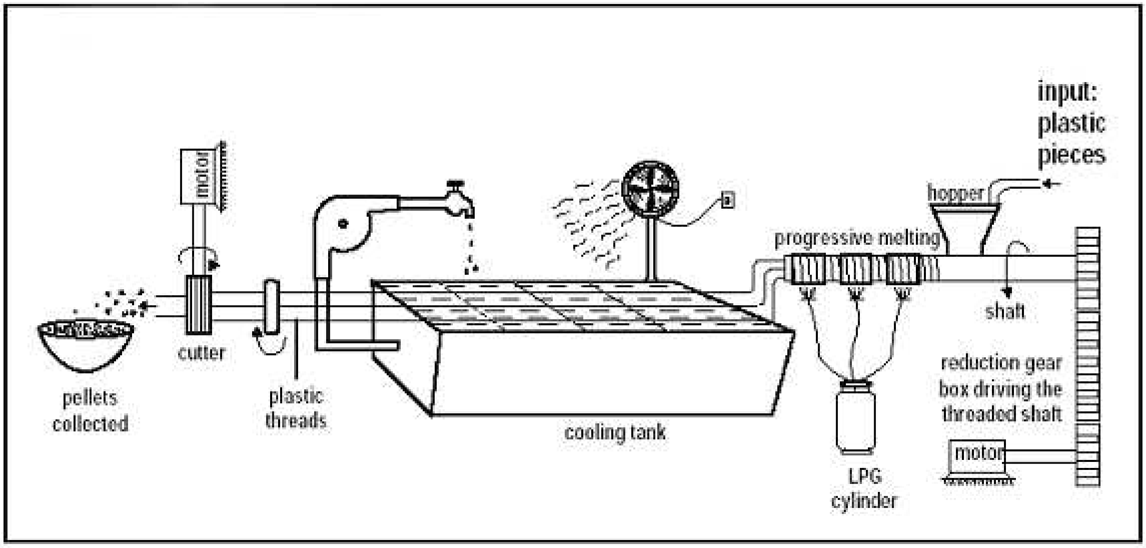

Figure 4: Pellet Formation in an Extruder Machine

The output from this heating process is passed over a cooling tank, and flows out in the form of strings, which are finally cut into granules, danas, or pellets by using a cutter attached at the output end. These pellets are then packed and either shipped directly to the plastic product manufacturers or to markets like Sadar Bazaar where they are sold as pellets.

When they reach the plastic products manufacturing units, mainly located in areas like Bawana, Narela, Anand Parbat and Mayapuri, these pellets are put into a mixer so that color or any other additives can be added to them. The pellets are usually mixed with virgin plastic so as to improve their quality; the percentage could be around 50%. These are then fed into molding machines in which the products are made.

4.2. Recycling Process of BFR Contained Plastics

Storage of the E-Plastic	 
Segregation of the Plastic by category	
Grinding of the Plastic by category	 
Differentiate the ground Plastic in plain and FR by use of salty water.	
Dry the ground Plastic in open area	 
Packing of the ground Plastic	

Storing and selling to the pellet making companies	 
Washing the ground Plastic by hand or machine in the pellet making units	
Drying the ground Plastic by dryer or in the open	
Treat the dry ground Plastic in mixture machine – making it softer and more pliable.	
Soft plastic put into an Extruder Machine for making string. Use of a water tub for cooling of the string and then cutting it by a cutter machine into pellets.	
Storing and selling the pellets. to the market and the industries	
In industries, mixing and adding the color to the pellets in the mixture.	

Manufacturing the product by mold in the molding machine	
Products	

Figure 5: Recycling Steps in the Informal Sector

4.3. Informal E-Plastic Recycling Market in Delhi

The informal plastic recycling market in Delhi is widespread, with around 600-700 pellet making units and more than 7500 workers involved in this process. For this study we focused on units dealing with plastics from E waste (E-Plastics), mainly HIPS and ABS. There are around 40 pellet-making units in Delhi, which deal with E-Plastics. The larger units in Bawana and Narela, employed on an average 8-10 workers, whereas smaller units in Karawal Nagar, Bhopura etc employed 4-5 workers involved in the various stages of the pellet making process.

Informal discussions with workers at these informal recycling plants revealed that the labor earned around 2000-4000 rupees monthly, whereas the skilled workmen earned around 5000-6000 rupees per month. Foremen or the supervisors were paid around 7000-8000 rupees. The labor force, consisting mainly of male workers, worked for 10-12 hours daily in these units.

Some of the smaller units are located on the plot sizes of 50-60 sq yards; the bigger ones have a space of around 200-300 sq yards. These shelters are generally temporary.

4.4. Occupational Health and Environmental Concerns

The recycling of plastic in the informal sector poses a huge occupational hazard for the workers. Apart from this, the machinery used is crude and it further increases the extent of the physical hazards caused by exposure to toxic materials like Brominated Flame Retardants. As is evident from various studies undertaken, BFRs are very loosely bound to plastics and they can be released in the form of dust during usage as well as by such processes. For the workers .inhalation of this dust during work hours may lead to their direct exposure to BFRs

In a study conducted at WEEE processing plants in Sweden by SJODIN ET AL. 1999 it was found that the workers at WEEE dismantling plants, a place where the air is laden with dust containing flame retardants, showed 70 times the level of one form of flame retardant compared with a control group. However, when conventional occupational hygienic conditions were established at the dismantling plants exposure levels dropped substantially. In India, these recycling units hardly observe any occupational hygienic conditions and hence might be at a higher risk of BFR exposure.

Another area that causes concern is the conversion of BFRs into brominated dibenzofurans, which takes place at a temperature higher than 230 degrees Celsius. Some of the processes may require the temperature to be higher than 230 degree, which may then lead to the formation of dibenzofurans.

Further research is required to establish the seriousness of the effects on health or the environment.

5. BFR Testing

The market flow study of E-Plastics indicates that there might be some serious concerns related to the recycling of these plastics. There could be a case of cross contamination as BFR contaminated plastic parts are recycled to produce different products

5.1. Cross Contamination

The issue of cross contamination is a very critical one and has hardly been looked into in India. It becomes critical especially in E- Plastics recycling, where BFRs have been added to make the plastic flame resistant. The plastic is recycled in the informal sector (as elaborated upon in the earlier chapter 4) where there are no processes to remove these contaminants. These recycled pellets are used to make new products like idols, decorative pieces, bike accessories and remotes etc and might be a source of BFR exposure in their new product form. As these pellets were being re-used without any inter mediatory step to remove the toxic flame retardant, we felt the need to test the recycled plastic pellets to determine the presence of BFRs. (The original plastic parts from computers were not tested as those clearly mentioned the presence of FRs). Among all BFR products, since PBDEs and PBB are of particular concern with respect to their impact on human health, the pellets were tested for their congeners.

Figure 6: BFR Presence in Computer Parts

5.2. Sampling

Pellets made out of recycled plastic from EEE were used for this study. The pellet samples were collected randomly during the field visits in Delhi, from the recycling units in Mundka, Bawana, Bhopura and Pooth Gaon that are situated at the hub of the plastic recycling in the city. The units, from where the samples were collected, specialized in plastic pellet making. The plastic samples were collected after the E-Plastics had been recycled to make pellets. This step was taken before these plastic pellets were used to manufacture new products.

Since HIPS and ABS are widely used in EEE casings, the plastic pellets made mainly of these resins were collected for testing. A total of ten samples were tested, that is four samples each of HIPS and ABS were tested under this study. Additionally, two samples of PC were also included in this study.

The trading and processing of plastic was wide spread in terms of the area and location of processing and hence presented a limitation in the form of establishing a direct linkage of WEEE to pellets.

The collected samples were sent to an accredited laboratory in Delhi to be tested for different congeners of PBDE and PBB.

5.3. Findings and Discussion

The data related to total concentrations of Brominated Flame-Retardants found in the plastic pellet samples are presented in Table 3.

Table 3: BFR Testing Results

Sample no	**Resin type**	PBDEs									
1	ABS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	358.4 mg/kg	4574.5mg/kg	1515.2 mg/kg	39602.5 mg/kg
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
2	ABS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	656mg/kg
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
3	ABS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
4	HIPS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Sample no	**Resin type**	PBDEs									
5	HIPS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
6	PC	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
7	PC	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	33.34 mg/kg	28.14mg/kg	864.4mg/kg
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
8	ABS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
9	HIPS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	140.9mg/kg
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sample no	**Resin type**	PBDEs									
10	HIPS	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	153.4mg/kg
		PBBs									
		Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octo	Nona	Deca
		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Brominated Flame-Retardants were detected in 5 of the 10 samples obtained for analysis. PBB was not detected in any of the plastic pellet samples, whereas different congeners of PBDE were detected in 5 pellet samples. Graphical representations of the same data are presented in figure 7. In the PBDE detected, Deca-BDE dominated the pattern in all the samples. The concentrations of PBDEs ranged from 140 mg/kg to 39602 mg/kg. Deca-BDE was detected in all five samples that tested positive for PBDEs. Additionally, two of these pellet samples were also detected with Octa and Nona congeners. The Hepta congener was detected in only one pellet sample.

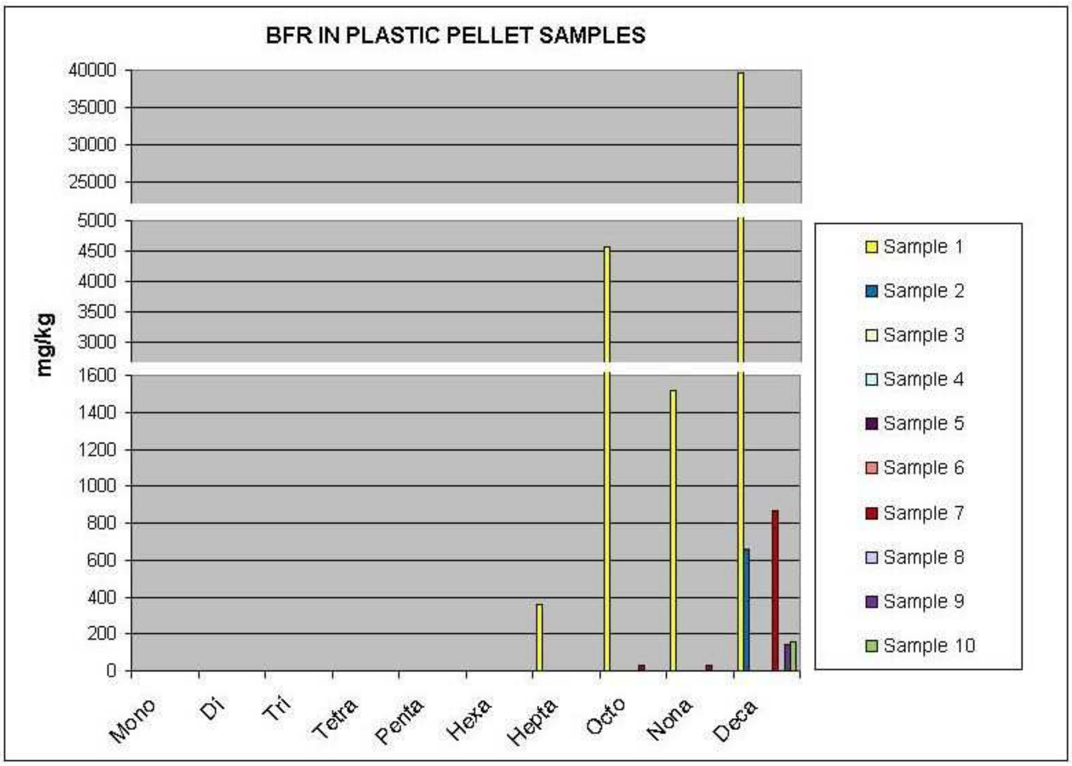

Figure 7: Total PBDE Concentration in Plastic Pellet Samples

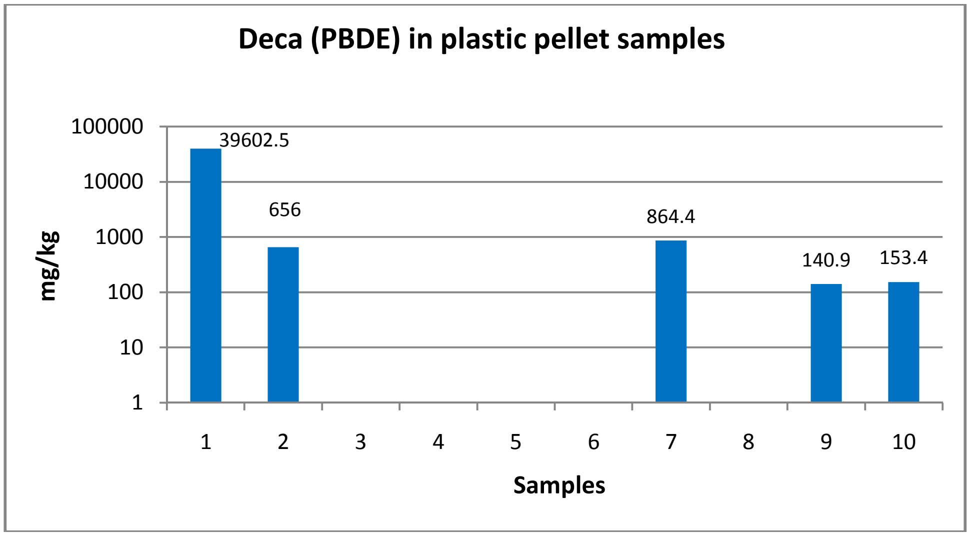

Figure 8: Deca (PBDE) Concentration in Plastic Pellet Samples

As mentioned above, Deca-BDE was found in five of the ten samples tested for PBDEs. The concentration of this congener detected ranged from 140.9 mg/kg to 39602.5 mg/kg as shown in Fig 8, confirming the wide usage of this PBDE congener.

A further analysis of the data points towards the detection of PBDE in all three different resins tested in the study. Samples of ABS, HIPS and PC were all found to have Deca-BDE, with two samples each of ABS and HIPS showing traces of this congener.

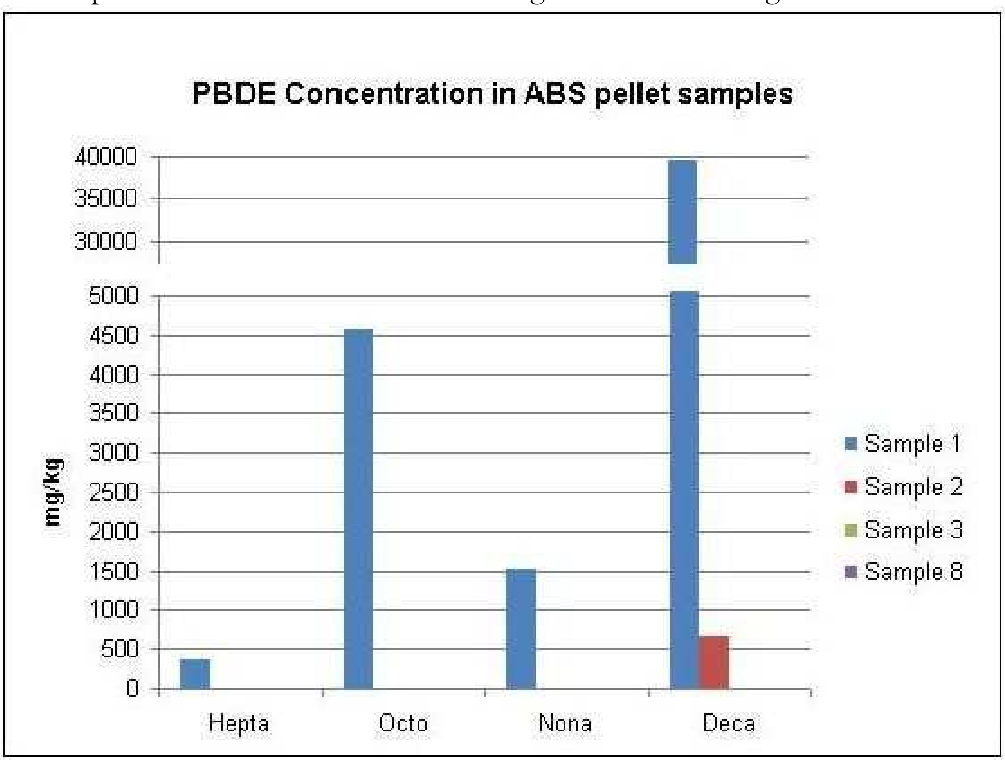

Figure 9: PBDE Concentration in ABS Pellets

Only four ABS pellet samples were tested for BFRs. While two samples were detected with BFRs, two samples did not have detectable limits of BFRs (fig 9). One of the ABS pellet samples was found to contain four different congeners of PBDE, namely Hepta, Octo, Nona and Deca. This sample also recorded the highest concentration among all the tested pellet samples, detecting 39602.5mg/kg of Deca BDE.

Out of the four HIPS pellet tested in this study, two samples were found to contain BFRs (fig 10). In contrast to ABS resin, HIPS resin was only detected with Deca congener of PBDEs. The concentration of Deca-BDE detected in these samples was similar.

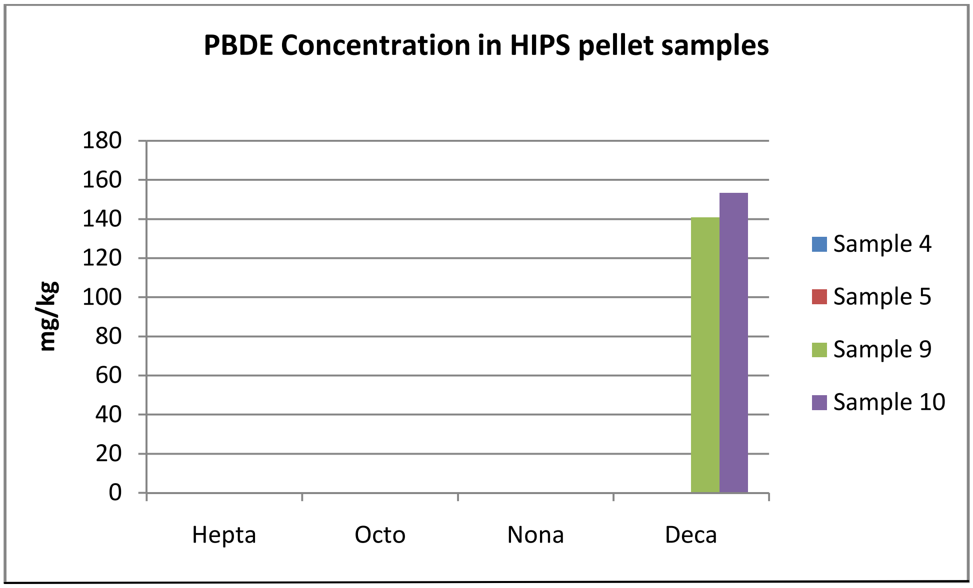

Figure 10: PBDE Concentration in HIPS Pellets

There were only two PC samples that were included in this study, as this resin type is not used very often for computer casings etc. One of the PC samples had detected a high concentration of Deca-BDE (fig 11). This sample was also detected with Octo and Nona congeners of PBDE.

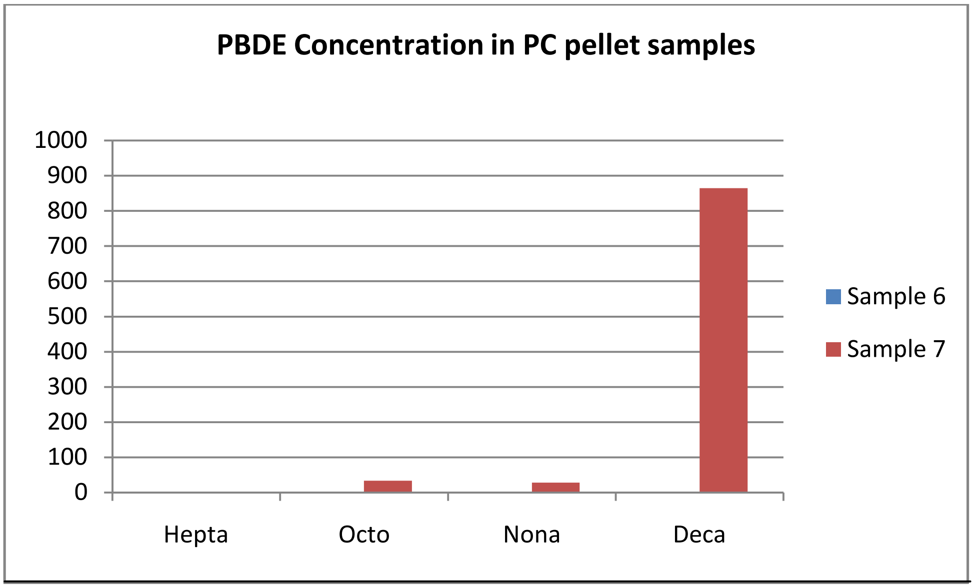

Figure 11: PBDE concentration in PC pellets

As mentioned earlier, the scope of the study permitted testing of only a limited number of samples. Hence it is difficult to draw any conclusive result, but the detection of PBDEs in fifty percent of the samples does suggest serious cross contamination issues. The only probable explanation for the BFRs being contamination in the plastic pellets is the use of Brominated Flame-Retardants in the original equipment as no flame-retardants were added during the entire process of recycling (as documented in this study). This raises serious concerns as these recycled plastic pellets are being used to manufacture new plastic products, some of these products do not require flame retardant properties. The results do indicate that there might be a case of the unintended presence of harmful toxins like BFRs in new plastic products. These household plastic products made out of recycled E-Plastic, contaminated with BFRs, might be a cause for toxic exposure to the users.

The findings do point towards the need for a larger study to observe the contamination in the pellets as well as in the new products.

6. Conclusion and Recommendations

Flame-retardants play an important role in protecting people and property by preventing damage caused by the spreading of flame and fire. The risk of injury or damage from fire involving EEE can be reduced significantly if fire retardants are present in them. Out of all fire retardants, BFRs are preferred, given their excellent fire retardant properties and low cost usage.

In the recent past, a great deal of controversy has revolved around the use of BFRs in EEE given their perceived impact on the environment and health. More than a few scientists have detected the occurrence of PBDE in soil, air, water and general biota. Researches have confirmed exposure of PBDE among people in areas where unsustainable recycling practices are adopted and contamination of the environment surrounding them. There has been an extensive debate about the environmental impacts of the recycling processes, in particular recycling through thermal treatment, due to perceived emissions of PBDDs and PBDFs in the combustion process.

The entry route of BFRs into the human body is through inhalation and ingestion and can cause serious health impacts. These chemicals are persistent in the environment and can also contaminate the food chain.

The presence of BFRs is likely to result in disruption of thyroid function, causing hyperactivity with disorders occurring in learning and memory. These chemicals share many common traits with PCBs including animal studies linking them to immune suppression, cancer, endocrine disruption, and neurobehavioral and developmental effects.

Plastic recycling units in and around Delhi handle both BFR laden and BFR free plastic in the same unit. The workers and handlers of plastic in these recycling units are aware of a separate category of plastic identified as FR plastic but are not aware of its hazards. The recycling process is undertaken in a semi open environment and the workers do not use any protective clothing while working on FR plastic. Studies initiated in some other countries have reported release of BFRs in the air and dust during the recycling of EEE.

The present low-end management system for waste plastics from WEEE in India raises serious concerns. The field study undertaken within this project suggests that the recycling process used in the informal sector may be a cause for occupational hazards as well as environmental pollution. The workers in the units may be exposed to BFRs released during the uncontrolled processes. Another concern is the conversion of BFRs into brominated dibenzofurans as the methods include heating (without regulation of the temperature) that are known to release these carcinogenic chemicals. The study of the recycling processes indicates the need to monitor and regulate these practices.

Fifty percent of samples tested in this study detected PBDE in varying quantities. The results of the samples tested point clearly towards the presence of BFRs in the recycled plastic pellets, thus raising the possibility of the unintended contamination of plastics and exposure of a large population to BFRs. The findings, though arrived at from a limited sample study, are alarming and warrant a need for a greater focus on this aspect and a more detailed study.

The study does suggest that this cross contamination has within it the potential of contaminating the complete supply chain of raw material leading to the manufacturing of products which do not require flame retardants. The FR plastic used in electronic products has markings suggesting it is FR laden plastic but the recycled products do not have any markings or labeling suggesting the presence of flame retardants.

A number of regulatory initiatives and decisions requiring the substitution of BFRs with halogen-free flame-retardants are being implemented or developed around the world. This has led to research and development of viable alternatives, with some major brands deciding to eliminate these chemicals from their products. The revision of the RoHS Directive in EU is in fact looking beyond PBDE and PBB and the stakeholders are demanding restriction on all bromine based flame-retardants. In India, currently there is no policy restricting usage of PBDE and PBB and hence companies are still putting products containing these BFRs on the market. There is a need for a shift by both regulatory agencies and private industries towards limiting the manufacturing and use of certain BFRs, especially the PBDEs and PBBs.

The materials containing brominated compounds need to be separated from end of life electronic products to reduce the contamination of those materials that can be recycled and reused in new products. New technologies are emerging to de-brominate plastics prior to recycling and these must be given priority over unsafe combustion based recycling of plastics with brominated compounds since this is likely to generate brominated dioxins.

The study does suggest the need to conduct a more extensive study to understand the release of BFRs into the air and soil in the recycling units as well as its levels in the workers engaged in recycling.

Key recommendations:

- Restrictions to be placed on the use of Halogen based flame-retardants in electronic and electrical equipments.
- Providing an incentive to companies with BFR free products
- Laying down specific standards for recycling of BFR contaminated plastics
- Facilitation of research studies by government departments and scientific institutions on BFR release into environment during recycling.

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