CHAPTER 2

LITERATURE REVIEW

2.1 DEFINITION OF PLASTIC

Plastics are artificial materials that can be changed to different products and goods through heat, grinding, forming and other methods. The root of this Greek term is "plastikos" which means formation. Since plastics are similar to resins, both terms are mistakenly used. Resins are gummy solid or semi-solid materials that are used in products such as paints, polish materials and plastics. A resin is called plastic when it is turned into solid at its final process. Plastic products are made from solid and processed resins (Ditrish, 2001).

The Society of Plastics Industry (S.P.I) in 1988 defined plastics as "a group of different and broad materials of which whole or part of them consist of carbon combination with oxygen, hydrogen, nitrogen and other organic and non-organic materials". The final products are in solid form. In some part of product process, plastics are turned to liquid to take any form such as granule, bottle and etc (Richardson, 2003). In general, plastics are organic material with high molecular weight that is produced by polymerization, i.e. chemical bonding of low molecular weight materials (monomers) into polymers. Properties of plastic material are determined by size and structure of polymer molecule. Some times, plastics are produced as pellets, liquids, powders and solutions (Hoo, 2006). Plastics can be produced from natural gas, coal, oil, and salt. However, oil from petrochemical industry still remains the main feedstock for plastic production because it supplies the monomers and polymers used (Waltera, 1991). Monomers and plastic resins with different properties are processed via different methods such as injection molding, rotational molding, blow molding, and extrusion (Aguado *et al.*, 2007).

2.2 ADVANTAGES OF USING PLASTIC

Plastics tend to be very flexible with a range of properties. Basically, plastics are relatively light, cheap, strong and durable; hence the widespread use. Appendix A shows some advantages and properties of plastics. Some peculiar advantages of plastic usage over other materials are:

- Plastics show durability, lightweight, strength and reduce cost over other materials, like paper, glass, wood, metal and etc.
- Plastic application are developed as based on the characteristics offered by the specific plastic; hence restricting it to that plastic.

2.3 POTENTIAL IMPACTS OF PLASTIC ON THE ENVIRONMEN AND HUMAN HEALTH

Plastic usage has potential impacts on the environment throughout its life cycle. Most plastics are landfilled when they are no longer useful to consumers. Though plastics may be regarded as highly stable materials, yet certain chemical compounds may be find their way into the environment considering their use and disposal which cause potential impacts to the environment and human health (Hoo, 2006). Plastics have benefits, but sometimes it threatens the environment and human health (Omrani, 2005). Some hazards could be due to ingestion of plastics. Exposure to sunlight especially increased levels of UVB has impact on plastics. Serious damage can only be made on plastics if there is significant ozone depletion. Also, the toxic substances particularly some plastic waste can contaminate the environment.

2.3.1 Disposal of Plastic Waste

Plastic waste can be disposed off using different methods (Appendix B) which include landfilling and incineration (Hoo, 2006). Recycling is another method to be considered. The advantage associated with recycling activities is the reduction of the waste disposed to the landfill and eventually reduction in the risks of environmental burdens (Pakhare, 2008).

2.3.2 Waste Recycled – Emissions and Energy Requirements

Recycling plastic waste into feedstock or into energy recovery is the key alternative to reuse option which is not environmentally sound way of extracting value. Recycling ensures that the intrinsic value is not lost. Therefore in industrialized countries, large scale plastic waste recovery is done via mechanical recycling and incineration. Some mechanical treatments like cleaning and shredding have been carried out on recyclates, the same as for the production of plastics from feedstock. Though most plastics are recycled mechanically, yet chemical recycling is sometimes adopted but it is still at a developmental stage. Plastic bottles form the bulk of materials collected and recycled from household waste. Recycling process requires energy and it generates some emissions into the environment (Hoo, 2006).

2.3.3 Emission Reduction

Recycling approach generated the least emission to the atmosphere. Energy recovery is marked by reduction in CO_2 and CH_4 emissions into the atmosphere. Besides, plastics can be incinerated together with other combustible products from the waste stream and this helps to reduce the quantity of greenhouse gases, such as methane gas emitted from landfills. Methane contributes more the CO_2 in terms of global warming (Hoo, 2006); hence the need to reduce quantity of waste from going to landfill.

2.4 CLASSIFICATION OF PLASTIC AND THEIR MAIN APPLICATIONS

The use of synthetic plastics has evolved since the late 19^{th} century in the packaging, construction, electrical, and the automotive industry. Plastics are classified as thermoplastic and thermosetting resins. Every group has special characteristics and different applications (Hoo, 2006). The main uses of some of the major plastics are shown in Appendix C.

2.4.1 Thermoplastic

Thermoplastics are completely polymerized and permanently fusible form of plastics that can melt upon exposure to sufficient heat; hence the potential to be recycled and reused. It refers to plastics which have linear and branched bonding in their structure. These plastics can be reformed due to the fact that the simple structure of their molecules can be heated, remolded, and covalently bonded for several times (Hoo, 2006; Smits, 1996).

Thermoplastics with crystalline microstructure are generally carbon containing polymers. The material distorts at specific temperature (Smits, 1996), but will always retain its newly reformed shape after cooling. This forms the basis of processing methods for thermoplastics. Examples of thermoplastics are polystyrene, nylon, polypropylene, polyethylene, cellulose acetate and polycarbonate. Approximately, 85% of all resins are thermoplastics while 70% of the total volume of thermoplastics is accounted for by resins (John and Timothy, 2003). They are precisely made in a variety of grades and due to their low cost, they are of are chosen ahead of others for large number of applications (Khorasani, 2005).

2.4.2 Thermoset

Thermoset plastics cannot be remolded and reheated. This is due to the fact that the bonds which are cross linked will have difficulty in recombining themselves (Hoo, 2006). These types of plastics can only be made once and cannot be recycled. Thermosets in the final form are big molecules which are not melted or solved and they become three dimensional lattice through heating under normal condition or though chemical reactions with additional materials in proper maundering conditions. Thermosets have high thermal stability and insulating properties (Khorasani, 2005).

2.5 PLASTIC RECYCLING

Generally, most plastics can be recycled and even new products can be formed from wasted plastic. Plastic recycling entails the process of recovering scrap plastics and reprocessing them to generate new materials that might be quite different from their original state. Plastic waste recycling includes collection and separation. The basic problem in recycling plastics is their variety. To solve this problem, separation of different types of plastic, a coding system for identification of plastic resins is introduced by the S.P.I in 1988. Thus, plastic containers are marked by codes which identify the type of plastic it is made from. This coding system makes the separation of plastic in recycling process possible (Khorasani, 2005).

2.1 2.5.1 Plastics in Malaysia

Plastics products and packaging are becoming more widely used in our daily life. Based on information released by Malaysia External Trade Development Corporation (MATRADE), the plastic products industry is viewed as a leading, most dynamic and vibrant growth sectors within the Malaysian manufacturing sector. The Malaysian plastics industries are basically a diversified sector and produce all sorts of products including household goods, bottles, containers and other packaging materials. It was reported (MATRADE, 2006) that about 2 million tonnes of resins for the plastics industry are produced locally per annum. Figure 2.1 indicated that the plastic production have been on the increase until 2010(MPMA, 2011). The increase of plastic products has direct relationship with the amount of plastic waste going to the landfill.

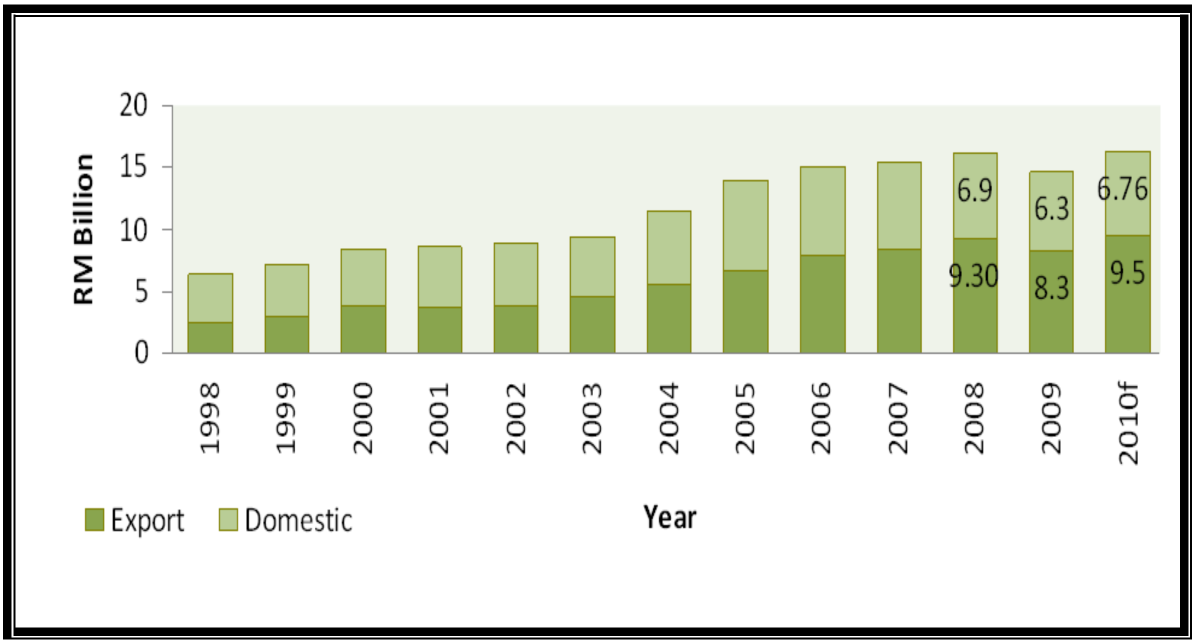


Figure 2.1: Trend of Plastic Production in Malaysia

Source: MPMA, 2011.

2.5.2 Plastic in Municipal Solid Waste (MSW)

MSW management is a big concern among the middle income countries like Malaysia (Ghani and Idris, 2009). Acute waste problems have been brought about by modern lifestyle. This is vivid with the quest for convenient packaging of products, and incessant spending due to high affluence that in turn generate more waste. Most often, wrappers from fest food outlets are discarded indiscriminately which makes the modern day waste to be characterized of much non- degradable material such as plastics.

MSW composition in Kuala Lumpur is divided into 8 categories namely organic waste, paper product, plastic, textile, rubber, glass, metal, and the others. Other category is defined as miscellaneous or beside the other major components. According to Figure 2.2, 15 % from the total composition of MSW in Kuala Lumpur is plastic. Organic waste is the major component of MSW in Kuala Lumpur while rubber, glass and textile have similar percentage, 1% each constitute of the waste stream (Mohamed *et al.*, 2008).

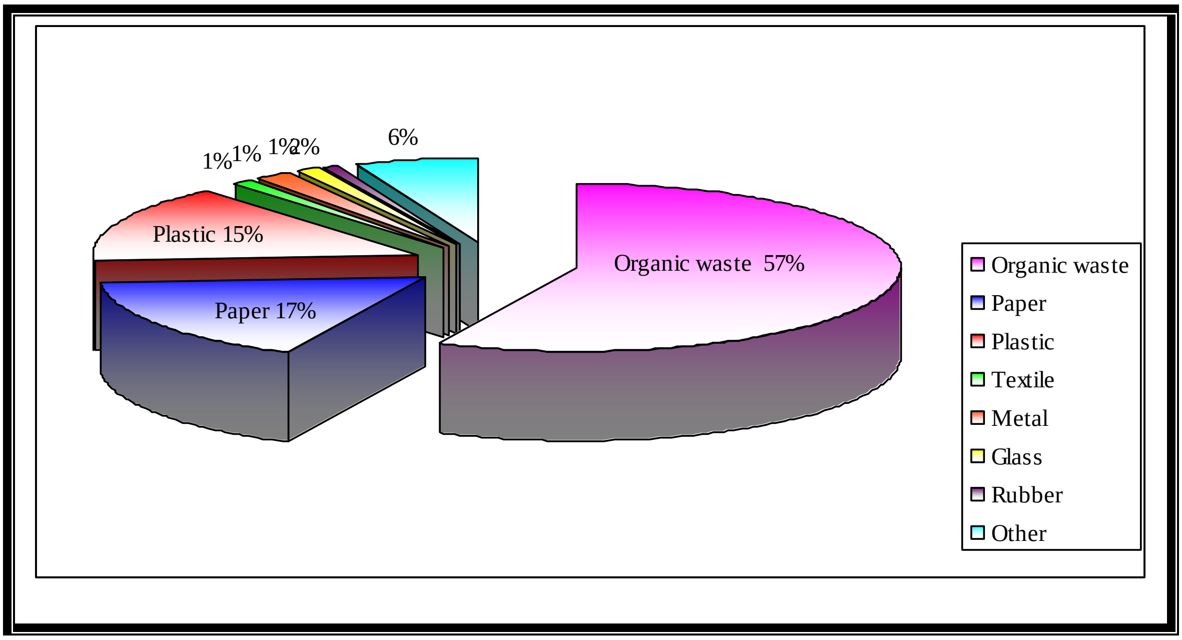


Figure 2.2: MSW Composition in Kuala Lumpur 2008 (Mohamed *et al.*, 2008)

Table 2.1 indicates that MSW in Malaysia is high in plastic content compared to other countries. In year 2008, 15% of MSW in Malaysia was plastics. Thailand contributed 11% plastic waste in MSW composition (Somtip and Cherdchan, 1998). Plastic waste in India is around 7% of the total waste generated in country. China only produced low plastic waste content 4.5% from total composition. It can be proved with increasing efficiencies of the new incinerators in China.

Table 2.1: Comparison of MSW Composition (FW %) between Kuala Lumpur with other Cities

Composition of MSW	Kuala Lumpur 2008	Thailand 1996	India 1999	China 1998
Organic waste	51	51	43	60
Paper	17	18	17	3
Plastic	15	11	7	5
Textile	1	1	0	1
Rubber	1	1	10	0
Glass	1	5	3	1
Metal	2	2	2	0
Other	6	9	20	30

Source: Mohamed *et al.*, 2008; Somtip and Cherdchan, 1998; Pieter *et al.*, 1999; Henderson *et al.*, 2000

2.5.3 Plastic Identification Code

The need to initially identify the category of plastic used for a specific product is very important. In Malaysia, the plastic products are classified into many categories such as plastics film, rigid shape (including bottles), foamed polystyrene etc. and a large part of the plastics products are used as packaging material including containers, wrappers etc.

for both industrial and consumer products. The coding system launched in Malaysia for plastics products divide plastic into 10 categories (Appendix D) (MPMA, 2011). Numerical coding system is used by many consumers to recognize various plastic types alongside the triangle of arrows. This was created by the SPI in the late 1980s which become the universal recycling symbol for costumers and manufacturers. Although there are only ten resin codes in Malaysia in the packaging of household products, yet about a thousand of different types of plastics abound. A combination of different dyes and additives when added to basic resin can produce a desired color, shape and texture of final plastic product. These manufacturing process variations result in different melting points of the plastics and even varying properties within the same resin code, hence the need for careful sorting after collection of plastic wastes. The identification code that is often seen at the bottom of plastic packaging assists the separation process of plastics (Mastellone and Perugini, 2005).

2.5.4 Challenges in Recycling Plastic

Plastics materials may be recycled, but in many countries recycling of plastics is still low. There are several technical and economic problems in the recycling of plastics; which can be classified into two general categories:

- the issues on segregation and identification of plastics and
- the economics of recovering because segregation and recovery costs for plastics can be very high.

Most plastic recycling industries in Malaysia focus on plastics scraps from industries or rejects from manufacturing/ productions. Recovery of consumer plastics is rather new in Malaysia but production of plastic pellets from consumer plastics were carried out by some industries in recent years. Detailed information on such recycling activities is not available and need to be investigated.

2.5.5 Recycled Plastic Types

2.5.5.1 PET - Polyethylene Terephthalate

PET as a thermoplastic polymer resin in the polyester family is used in producing synthetic fibers. The chemical structure of PET is shown in Figure 2.3. Glass fiber often combined with beverage, food and other liquid containers via use of thermoforming applications and engineering resins. Infect, PET is one of the most important raw materials utilized in the production of artificial fibers. PET has good barrier properties against oxygen and carbon dioxide.

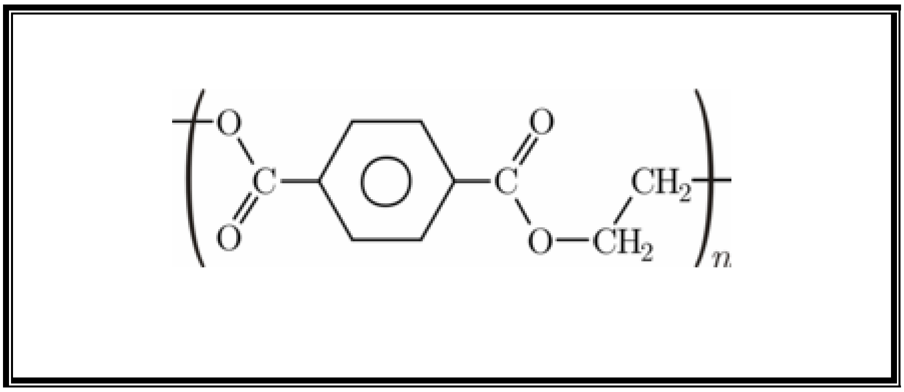


Figure 2.3: Chemical Structure of Polyethylene Terephthalate (PET)

PET molecules like other polymers are formed from long chain repetition of carbon, oxygen and hydrogen unit. Figure 2.3 shows PET structure which is the repetition of the molecular unit. Usually the number of N is 100 to 200 (Omrani, 2005).

PET are potential very resistant to mineral oils, acids and solvents but not to bases. It can be recycled several times before losing some of its quality. It is naturally colorless with high transparency and is a semi-crystalline class of thermoplastic material. PET is a material with high insistence and low weight, large-capacity and low thickness from polyester. PET being a common consumer plastics, is used in producing various types of drinking bottles, water, oil, cosmetics, edible oils, cleanings detergents, pharmaceutical products and other food and non-foods containers (Waltera, 1991). Fast and global growth of PET bottle demands is very observable during 1990s in Europe. Thus, the rate of consumption of these bottles has increased from 300,000 tonnes to 1.5 million tonnes, and similar increase is also evident in other parts of the world (NAPCORE, 2007).

PET is used for the first time in producing synthetic fibers in 1941 (NAPCORE, 2007). The use of PET in industrial packages in 1970 started with the production of normal bottles. Nowadays, PET is mainly used for the production of bottles. PET production started from raw material of ethylene and parazylene compounds. These two materials with ethylene glycol and terephtalic acid form PET resin. This resin which is formed in small cylinders will be melted and poured inside the final mold. This mold will be in the form of bottle under pressure and will be blown. High resistance of these bottles distinguishes them from other materials. Because of molecular characteristics of PET which is formed during the blowing and resin formation, drinks with carbonic gases will easily remain in these bottles and will not undergo change due to pressure (Bisio and Xantos, 1994).

PET containers can be fully recycled. Their distinction from other materials is not only because of their recycling feature but also because of their low weight. By reducing PET containers’ volume, less space in transportation will be utilized. Also their low weight will consume less petroleum in transportation which will save energy (Saatniya, 2002).

The materials formed from PET are used in daily life. Other features of PET are its low weight and thinness in packaging industries which make contents visible. From other physical characteristics, its' well-formation feature enables the molding into different shapes (Showartez and Godman, 1999). This plastic melts at 255 C° as it is shown in Appendix E. If it is cooled quickly, it will totally become formless and its density will change (Omrani, 2005).

PET's toughness allows its broad applications. Camera film base and record tape are the main products of this process. This film can be used for a long time in projector without breaking or considerable erosion. Regarding its resistance against moisture, the film is used in packaging industry, food production and also as insulator in transformators. Also, they are used in cable covers due to their characteristics of toughness in films with low thickness.

Polyester fibers of PET have excellent elasticity and high resistance against crumpling compared to other weaving fiber. PET characteristics are better maintained when wet. Thus, pleated cloths and dresses made from this fiber will not change after washing and drying. The characteristics of this fiber make it useful in producing cloths that need no ironing.

In recent years, the productions of drinking bottles from PET are highly noticeable. PET has excellent brightness and gleams. It has high insistence against penetration of carbon dioxide, oxygen and water while it has considerably low weight when compared with glass bottles. These are the reasons that make the production of drinking plastic bottles increase rapidly over the years. Also, the production of PET bottles is cheap. PET bottles have high strength against impact and crack such that the bottle will not break easily. When it is melted and blown, hydrocarbons can’t penetrate. If there is no caution in the procedures of generating PET, staldeid will be created. This staldeid can change the taste of non-alcoholic drink. However, with the use of the best condition in injection molding (keeping it in exposed heating), concentration of generated staldeied will be very low and drinking taste will not change. In most countries, PET bottles are thrown with other domestic wastes and incinerated. It causes environmental pollution (Omrani, 2005).

2.5.5.1.1 Types of PET

There are four types of PET with different features.

A.PET

The real differences between A.PET and PET as two polymers are not obvious and somehow are same. A.PET is similar to bead or pill and structurally is crystalline. It becomes bright under formation process such as extrusion.

C.PET

This material is known as crystal Polyethylene Terephthalate. It is always turbid but in natural state it is cream in color. This material is used in the production of polystyrene containers for microwave ovens. Formation process of this resin is similar to other polyesters but it needs more consideration to keep humidity rate lower than 0.003%. High humidity causes reduction of its stroke characteristics.

G.PET

Glycol Polyethylene Terephthalate is a polycoplyester which has more nonlinear molecule chains. This material with PVC is used in capsule packages and pills. Due to its similar characteristics and cost with some of polycarbonates and acrylic, it is used in packaging.

R.PET

Returned PET material is shown with R.PET abbreviation. Previously, before the advent of primary polymerization of monomers in chemical reactors, producers of resin use returned material in reactors. Nowadays R.PET materials are used in different ways. Weaving industry is the biggest consumer of R.PET but new markets are opening to produce consumers' products and goods at lower price. R.PET is usually prepared as non-crystal flakes or crystal pellets which is mainly sourced from drinking bottles (Waltera, 1991).

2.5.5.2 HDPE - High Density Polyethylene

Another thermoplastic made from petroleum is HDPE which is in polyethylene form. HDPE possess stronger intermolecular forces and tensile strength than lower density polyethylene. In fact, HDPE is simply the high density version of PE plastic. It is heavier, harder and stronger than LDPE, though less elastic. HDPE can be machined, molded and joined together via welding because its less dense than water. It is also very resistant to many alkalis, solvents and acids, and possess variety of applications potentials; hence can be used in production of children's toys, plastic bags, etc (Lou *et al*., 2007).

2.5.5.3 PVC - Polyvinyl Chloride (vinyl)

PVC is a heavy, ductile, stiff and medium strong amorphous material. It has good resistance to bases and acids, but is often affected by some solvents. Soft PVC is very resistant to most chemicals and PVC is basically one of the best recyclable plastic which has similar quality to that of virgin plastic, as shown in Figure 2.4. PVC tubes do not bend and possesses good barrier properties to atmospheric gasses. Most insulators for pipes, electrical wires, etc are made in PVC form (Lou *et al*., 2007).

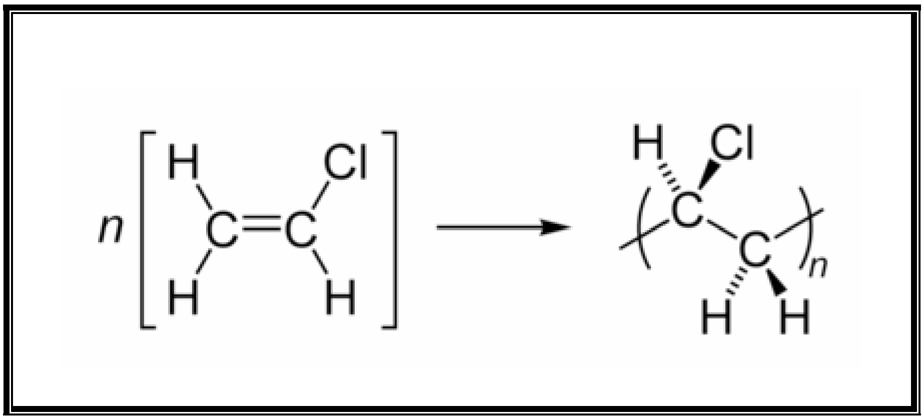


Figure 2.4: Polymerization of the Monomer Vinyl Chloride

2.5.5.4 LDPE – Low Density Polyethylene

LDPE is also a thermoplastic made from oil and just is the low density version of PE. The degree of its strength, hardness and stiffness is less when compared to HDPE, rather it possesses better ductility. It is characterized of an opaque nature and only thin foils can be transparent. LDPE also has excellent resistance to water, moisture and most organic solvents and chemicals. LDPE is commonly used in the production of various containers, dispensing bottles, wash bottles, tubing, plastic bags for computer components, and some other molded laboratory equipment (Lou *et al*., 2007).

2.5.5.5 PP – Polypropylene

PP is another thermoplastic polymer produced by the chemical industry and used in a wide variety of applications for including food packaging, stationery, textiles, ropes, reusable containers and plastic parts. Characteristics of PP range from being low in strength, inexpensive material with reasonable outdoor performance to ductility, as shown in Figure 2.5. It possess a waxy surface, scratches easily, opaque like and white coloration though can be dyed in many colors. PP is very combustible and additives can reduce its inflammability. Like LDPE, it is also resistant to bases, water, acid, moisture and some solvents (Khoo, 2009).

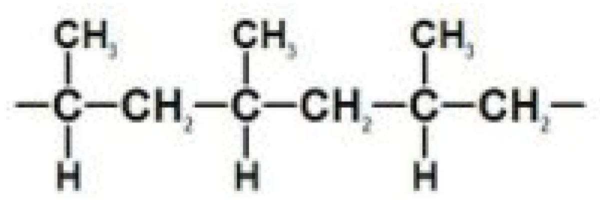


Figure 2.5: Chemical Structure of Polypropylene (PP)

2.5.5.6 PS – Polystyrene

Another form of thermoplastic which normally exists in solid state at room temperature, but melts if heated, and solidify again when cooled is PS. Styrene monomers pose serious threat to health and the structure is shown in Figure 2.6. PS is also an inexpensive amorphous thermoplastic that is vitreous, brittle and has low strength, though stiff and hard. PS in a foam form is used for packaging and insulation purposes.

It is transparent (transmits about 90% of the sunlight) and can be continuously dyed. Also resistant to acids, water, and detergents, but it generally dissolves in almost all solvents. It is used in the production of disposable drinking glass, biodegradables, razor, etc (Lou *et al*., 2007).

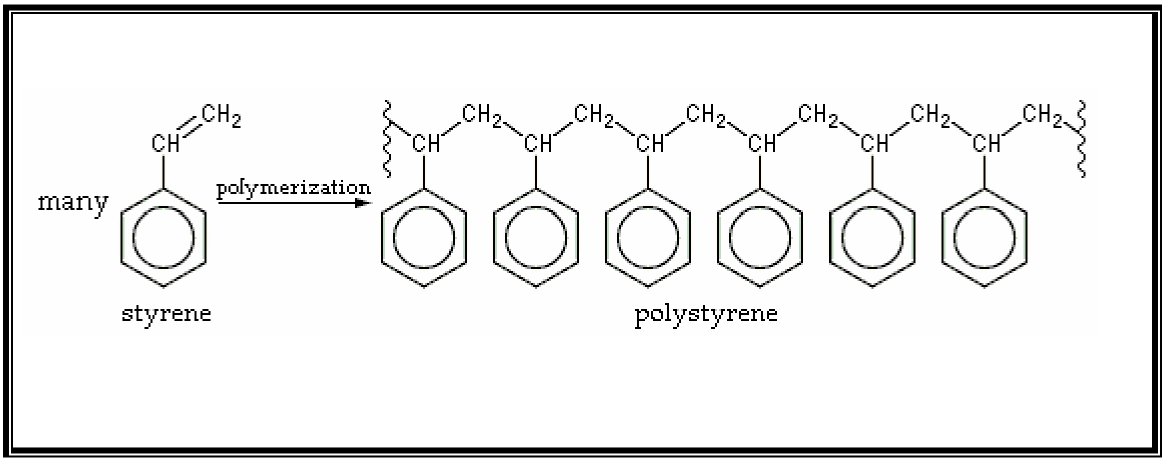


Figure 2.6: The Chemical Makeup of Polystyrene is a long Chain Hydrocarbon with every other Carbon Connected to a Phenyl Group

2.6 PET RECYCLING HISTORY

PET bottles were generated the first time by Nathaniel Vic in 1973. The first process of PET recycling is done by Saint Jude Polymers Company in 1976. Their first products from recycled PET were strap and paintbrush. This company for the first time started making consumed plastics of PET palletizing in 1977. This act is considered important pace because many companies of PET production in their processes rely on fractional plastics. With this act a variety of productions from used PET and recycled PET can be increased. The main growth in developing demand and capacity for used PET recycling happen when a plastic weave factory called Wellman began its operation. In early 1978, Wellman started recycling of PET bottles in the form of weave product for carpet and other proper weave products. Wellman increased the recycling of used PET and increased the capacity of the process as a result of market demand for PET consumption during 1980s until 1990s. Other important event was producing the first fiber weave in 1993. It was a production of 100% of PET recyclables called Ecospon which is now the most familiar material in sport clothes. Nowadays, with the operation of many companies and that of Saint Jude and Wellman, the capacity of recycling action is totaled to more than 2 million pound recycled PET resin annually. About 1.5 million tonnes of PET is collected worldwide every year. In fact in 2007, about 1.13 million tonnes of PET bottles were collected in European alone as stated by Petcore, the European trade association that ensures collection and recycling of PET. This consists of more than 40% of the total number of bottles. With recent developments in PET recycling techniques, the access to this technology become possible in which containers and bottles and even some food packages are recycled and reused (Hurd, 2000).

2.6.1 PET Recycling

In the recycling industry, "post-consumer PET" means referred to discarding of the empty PET packaging by the consumer after use which becomes PET waste (Figure 2.7). Many local governments and waste collection agencies often collect post-consumer PET separately from other household waste. In some places, the collected post-consumer PET is taken to recycling centers also known as materials recovery facilities (MRF) for discrete sorting from other materials like metal, HDPE and PVC products, and even flexible plastics of low density polyethylene.

Figure 2.7: Cycle of PET Bottles

2.6.2 Collection Method

World over, there are four basic ways in which communities offer recycling collection services for plastic bottles and containers to their residents. In some areas the ways of collection is similar, while in other areas it is the combination of several methods. Plastic is an ideal material for recycling and can be reprocessed multiple times because the source material is available in large quantities (often as a 'mono-material').

Presently, focuses have shifted to PET bottles which are collected in dedicated collection systems (NAPCORE, 2007) or sorted from other waste streams. Some countries are planning to or have already adopted legislation to reduce packaging waste by the following approaches:

- Imposing ban on disposal of packaging waste
- Instituting collection rates
- Adoption of reuse or reprocessing quotas (WRAP, 2008).

PET bottle recycling is increasing steadily, and this effect is compounded by an overall increase in consumption and collection rates in some markets. It is expected that collection of PET bottle may double in the next five to six years on a global scale, whereas values for Asia-Pacific and Europe rim are expected to triple.

According to consultant group PCI (PET Packaging, Resin & Recycling) in 2005, about 2.5 million tonnes of PET bottles were recovered with about 70% coming from Asia Pacific and Europe. Regionally, China recovers 50% of Asia Pacific's PET bottles, with impressive reported-collection rates of 90%. Preliminary reports opined that top recyclers will remain the same: Asia Pacific (1.8 million tonnes), Europe (1.1 million tonnes), North America (721,000 tonnes), South America (231,000 tonnes) and Africa/Middle East (34,000 tonnes) (Figure 2.8) (Claudio Bertelli UOP Sinco, 2010).

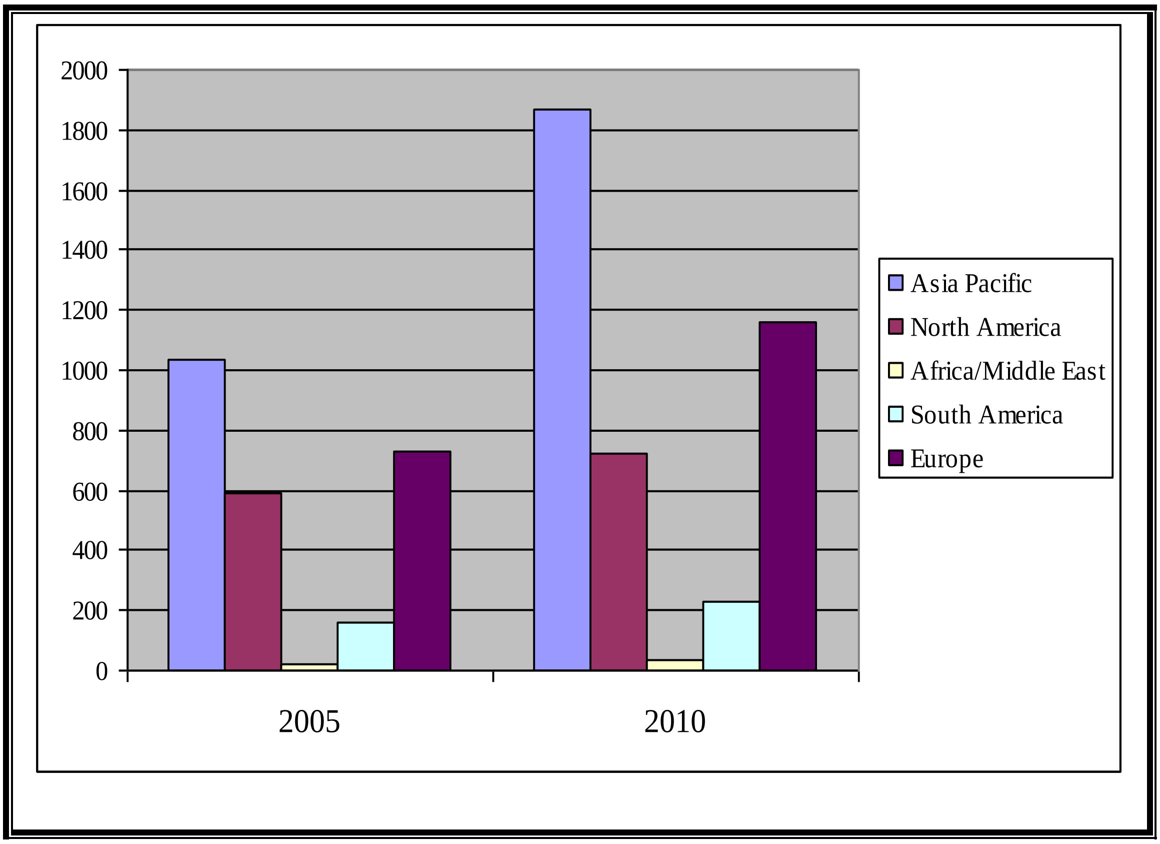


Figure 2.8: Worldwide PET bottle Consumption and Collection

Reused PET food-contact bottles is quite a small fraction of all recycled PET. In 2005, food-contact bottles accounted for only 9% of worldwide post-consumer PET. Estimates had shown that by 2014, 600,000 tonnes of PET bottles will be collected in Europe, and will be recycled back into recycled directly back into bottles—an increase of 68% from 2005 (Claudio Bertelli UOP Sinco,2010; Petcore 2004).

2.6.2.1 Drop-off Centers Method

In drop-off recycling centers, containers for designated recyclable materials are placed at centralized points like schools, churches, parking lots, and etc. The containers are properly labeled to indicate the type recyclable material to be placed in them. Residents are then required to send their recyclables to the drop-off location, where recyclables are separated by material type into their respective collection containers. Drop-off centers need much less investment to establish unlike curbside programs, yet do not offer the convenience of curbside collection. However, drop-off collection centers work well in rural locations where curbside collection is impractical, than in urban centers. Approximately 10-15% of materials are collected with this system and if the awareness of public increases, this rate can be enhanced to 10-30%. This system of collection is so common in USA and it is also used in some countries such as France, Swiss, and Italy. It is a low cost system that can be used for every kind of recycling materials (Lisa *et al.*, 2007).

2.6.2.2 Curbside Collection Method

Curbside collection is the most widely accessible collection method and curbside recycling programs very easy for community participation, as its recovery rate is high. According to Center for Plastics Recycling Research at Rutgers University, a study showed that curbside collection gathers 70-90% of available recyclables. Similarly, estimates by the National Association for Plastic Container Recovery (NAPCOR) indicate that about 55% of all the PET plastic containers collected for recycling are generated via curbside programs. Communities that use curbside collection advise the residents to sort discrete recyclables from their household waste and to place them into designated containers, so that the municipal crews will collection them later. In this method, generally 40-60% of used materials can be recycled and it leads to the reduction of the total costs. Also public participation has much more important role in this system of collection.

However, some communities allow their residents to mix up the recyclables. Some communities observe daily collection of recyclables while others have scheduled days for trash collection and collection of recyclables. For better separation of materials from waste, it needs citizens' education and training (Hurd, 2000).

2.6.2.3 Buy-back Centers Method

Communities do not provide this buy-back service in the real sense. This is because most of the buy-back recycling centers are operated by private companies. Incentives are provided via legislation or loan programs in order to assist in the establishment of buy-back centers for the residents. Buy-back centers pay some amount to consumers for every recyclable materials that are brought to them. Most buy-back centers require consumers sort their recyclable materials at source before binging over for sale, and they may even be required to remove caps from the bottles. Such purchase specifications help to reduce contamination levels and enable the buy-back center to embark on immediate processing of the recyclables they purchase, while making economic incentives available for consumers to comply with the specifications.

Basically, this method is made possible due to statewide laws have passed such legislation that assigns a redemption value on carbonated beverage containers. This method of returning such containers facilitate recycling by aggregating large quantities of recyclable materials at the beverage retailers and wholesalers shop in readiness for collection by recyclers(Pakhare, 2008).

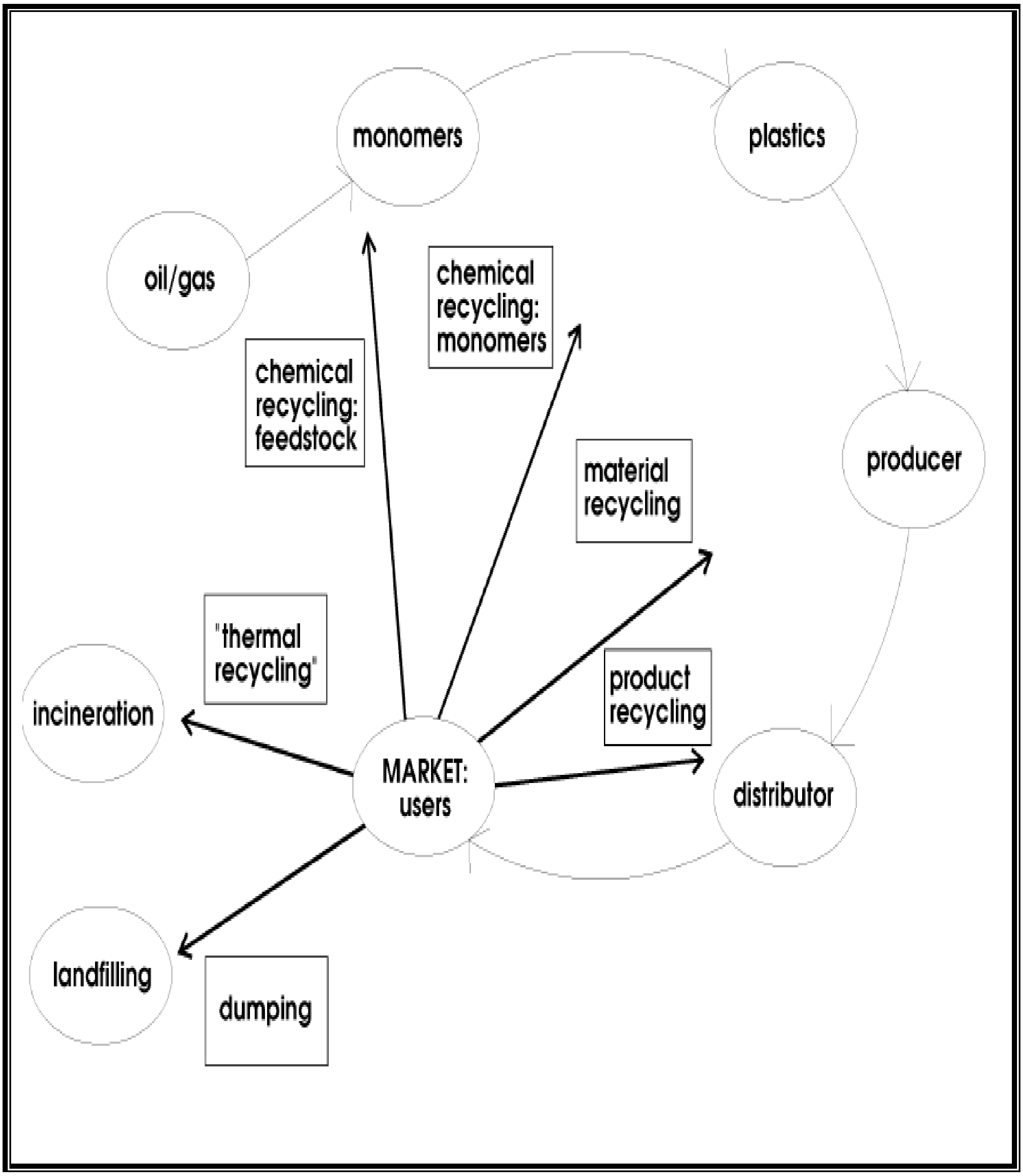
2.6.2.4 Reverse-Vending Machines Method (RVm)

This method is a kind of buy-back centers system but in small scale. The Reverse-vending machines placed at public places. Citizens are paid based on the recycling containers returned. The RVm machines are designed with some especial features in which citizens must conduct minimal source separation such as removing caps from bottles (Figure 2.9). Consideration of these characteristics can reduce the rate of pollution. Approximately 15-20% of recycled materials are collected with this method (Lisa *et al.,* 2007).

Figure 2.9: Reverse-vending Machines

2.6.3 PET Recycling Methods

The separation of the recyclable plastics into discrete resin types or fractions marks the beginning of PET recycling. It can be recycled via three methods: mechanically, chemically and energy recovery (Finger 2.10).



Finger 2.10: Plastic Life Cycle and Corresponding Recycling Options

2.6.3.1 Mechanical Recycling

Mechanical recycling of PET basically entails the shredding, granulation and melting plastics waste. Proper separation of PET materials must be sorted prior to mechanical recycling. Mechanical recycling is simply a method adopted to make new products out of unmodified plastic waste and it had been successfully practiced by recycling companies which collect industrial scrap and reprocess them through activities of sorting, cleaning and re-pelleting using an extruder to produce uniform pellets. It is then sold to the plastics industry for production of new products (Appendix F).

After PET bottles have been sorted from household waste, they are compressed and packed by municipalities before transporting them to recycling plants, where impurities are removed, and the container is subsequently shredded, cleaned from foreign bodies and separated of non-resins. The remaining component is turned into pellets and flakes for recycling. The generated materials (recycle) are then sent to textile and sheet-making plants, and will be melted again with other processes to produce textile and sheet products.

After PET bottles are collected, it may be mixed with other bottles such as heavy polyethylene, PVC, and papers. Thus, these bottles are transferred to sorting unit. In mechanical recycling, cyclone separators are used to remove paper labels which are contaminants as the plastic is shredded or crumbed into flake forms. The process also involves washing of flakes, drying and pellet extrusion for the market; hence mechanical recycling of PET undergoes eight (8) different steps.

Step 1 - PET Collection

As it is mentioned before, PET for recycling comes from post consumer PET which has already been used earlier by people. These are the plastics obtained from plastics recycling bins and even at domestic roadside collections.

Step 2 – Sorting

Post-consumer PET must be sorted into different color fractions namely; transparent or uncolored PET, green and blue colored PET, while the remainder is classified as mixed colors fraction (Figure 2.11). The appearance of new colors (like amber for plastic beer bottles), complicates the sorting process for the recycling industry (Torres *et al.*, 2000).

Figure 2.11: Bales of Crushed PET Bottles

Therefore, the post-consumer PET waste is crushed, compressed into bale forms in readiness for sale to recycling companies. Transparent post-consumer PET attracts higher sales prices when compared to the green and blue fractions. The least valued is the mixed color fraction. PET is sorted manually or automatically.

Step 2-1: Manual Sorting

The collected PET in recycling place is usually sent for strappings where workers separate PET manually according to their features such as shape, color and etc. Sorting

PET bottles from other plastics is simple because PET bottles are brighter than other plastics such as PVC bottles and their bottom has different shape than other plastics. For example PVC has a cutting line at the end and heavy polyethylene bottles are turbid and they also have a cutting line at the end. Each worker is responsible for sorting specific type of plastic bottles.

Step 2-2: Automatic Sorting

There are different ways for automatic sorting of PET bottles which are:

- Florissant spectrum with X-rays. This method is used for separation of PET bottles from PVC bottles.
- Infrared spectrum: which recognizes the spectrum of each material and complicated sorting is possible with this method.
- Light sensors: which are used for sorting plastic bottles according to their brightness and color based on visible spectrum.

These methods can sort plastic bottles with high precision according to the color of the polymer type. In these methods all kinds of bottles are thrown over strapping before being scanned separately and their type and color distinguished according to basic information. Then air blowers fling these distinguished bottles with air pressure over strappings to sorting places and channels of the same bottles. The use of these methods needs high investment (Figure 2.12).

Figure 2.12: Separating of Plastic Types

Step 3 – Compressing

Transportation of PET bottles has low cost and its transportation to other units is easy. It needs to be compressed by a vertical and horizontal compressor. In both methods, bottles are shredded and flattened by hitting sheet. This cycle continue until a pack of fully compressed bottles is produced. This compressed bale of PET bottles is covered with metal rope. Sometimes bottles are passed through punch machine before compressing. This machine pierces bottles and releases the air inside the bottles to increase density of compressed bottles.

Step 4 – Chipping

Chipping process takes place after the sorting. This is done using the chipper; a cylinder of blades that resembles an old-fashioned lawnmower inserted in a vessel with a 10 mm grid floor. The blades make fine cuts of the material until it is small enough pass through the grid (Drying, 2004).

Step 5 – Washing

Washing is the next stage and is very important for the removal of paper labels, glue, dirt and any remnants of the product which might still be attached on the chip. It takes about 12 minutes to wash both the "other" stream and the PET stream at around 90 C°, using an alkaline detergent wash solution in water, as it helps to removes dirt, grease and degrades protein. Finally in the process of washing, the agitator in the wash tank functions as an abrasive, grinds off the glue of the labels and reduces any paper labels to fibers. The glue paper and other dirt components are finally forced out through small holes while the plastic stays intact.

Step 6 - Floating Tank

In this step, density differences are used to separate plastics. It is done using water cyclone which is effective and of low cost. It can separate plastic or non-plastic materials from the recycling components. This process not only increases the rate of production but also takes fewer stages than other separation methods. For hydrocyclones, density is the effective factor that helps in its separation. An increased differences between materials, enables a probability of separation. The plastics are further rinsed and then separated in the PET stream based on their weight. Water cyclone is designed to separate out the given plastic from others (Figure 2.13).

Figure 2.13: PET Recycling Line- Sink-Floating Tank

Plastics such as polyethylene (PE) or PP with low density and lighter in weight will float in water while plastics such as PET which is heavier will settle at the bottom (approximately 95%). Unfortunately, PVC has same weight as PET and it settles down with PET in this stage. Thus, it is better to remove all of PVC during manual sorting (Tukker, 2002).

Step 7 - PET Flakes

The recycling firms/ industry often conduct more treatment on the post-consumer PET via shredding the material into small fragments. Such fragments may still residues from the original state, shredded paper labels and possibly the plastic caps. Different processes are used to remove the above which lead to generation of pure PET fragments, or "PET flakes" (Figure 2.14). Standardized PET flakes serve as raw material for many products that would be made of polyester (Appendix G). Polyester fibers include strapping, PET bottles or polyester sheets. It even serves as base material used in the production of carpets, pillows and some other clothing materials (Golami, 2005).

Figure 2.14: PET Flakes

Step 8 – Pelleting

Pelleting is a process of melting the flakes and extruding them out via a fine grill in order to remove any solid dirt or metal particles. In order not to allow entangling of the extruded plastics, it is the sprayed with water immediately it comes out and subsequent by cut off by rotating knives to give small, oval pellets (Figure 2.15) (TEI and Sasaki, 2006).

Figure 2.15: Pellet of PET

2.6.3.2 Chemical Recycling

Chemical recycling involve a more complex process because the plastic polymer needs to be broken down into the monomer form before being re-polymerized. This stage/ process make the recycled product to look very similar like the virgin material. However the method is limited to certain resins especially PET. Chemical recycling of PET depends on the chemical reactions which break down the PET into small molecules. This can then be used as chemical feedstocks, either for re-polymerizing PET or for manufacturing related polymers. Two procedures, glycolysis and methanolysis, are in commercial use. Both can be used to produce PET which is chemically identical to virgin polymer. It has been approved for food –contact use (Karayannidis and Achilias, 2007).

Typical glycolysis processes produce partial depolymerization, which is followed by purification and repolymerization. Methanolysis processes provide full depolymerization, followed by purification by crystallization and then repolymerization. Glycolysis cannot remove colorants and certain impurities which can be removed by methanolysis. DuPont also operated a methanolysis facility for PET recycling. However, recently they hold discontinued the operation for economic reasons. methanolysis is the major chemical recycling production that is commonly used. However, the expenses incurred to obtain monomers via chemical recycling process is much higher that use of traditional chemistry (Sinha *et al.*, 2008).

2.6.3.3 Energy Recovery

Energy recovery is a major growing part of integrated waste management; just like using municipal waste as source of fuel to generate heat or electricity. All inorganic materials possess energy in form of carbon. Obviously, law of thermodynamics stated that energy can neither be created nor destroyed but can be transformed from one form to another. MSW is comprises of inorganic materials such as glass, metals and even organic materials such as food waste, paper and plastics. However, excluding the inorganics, all other materials have a high value that varies from one material to another. Energy recovery differs from fuel recovery because recovered fuel is mainly a manufactured product that is produced with the intention of meeting the market specifications, while energy recovery plants are designed to ensure complete burning of waste or for minimal sorting of wastes (Mastellone and Perugini, 2005). Thermal recycling also involves breaking down the chemical structure of the polymer. In this case, instead of relying on chemical reactions, the primary vehicle for reaction is heat

(Figure 2.16). In pyrolysis for example, the polymer (or mixture of polymers) is subjected to high heat in the absence of sufficient oxygen for combustion.

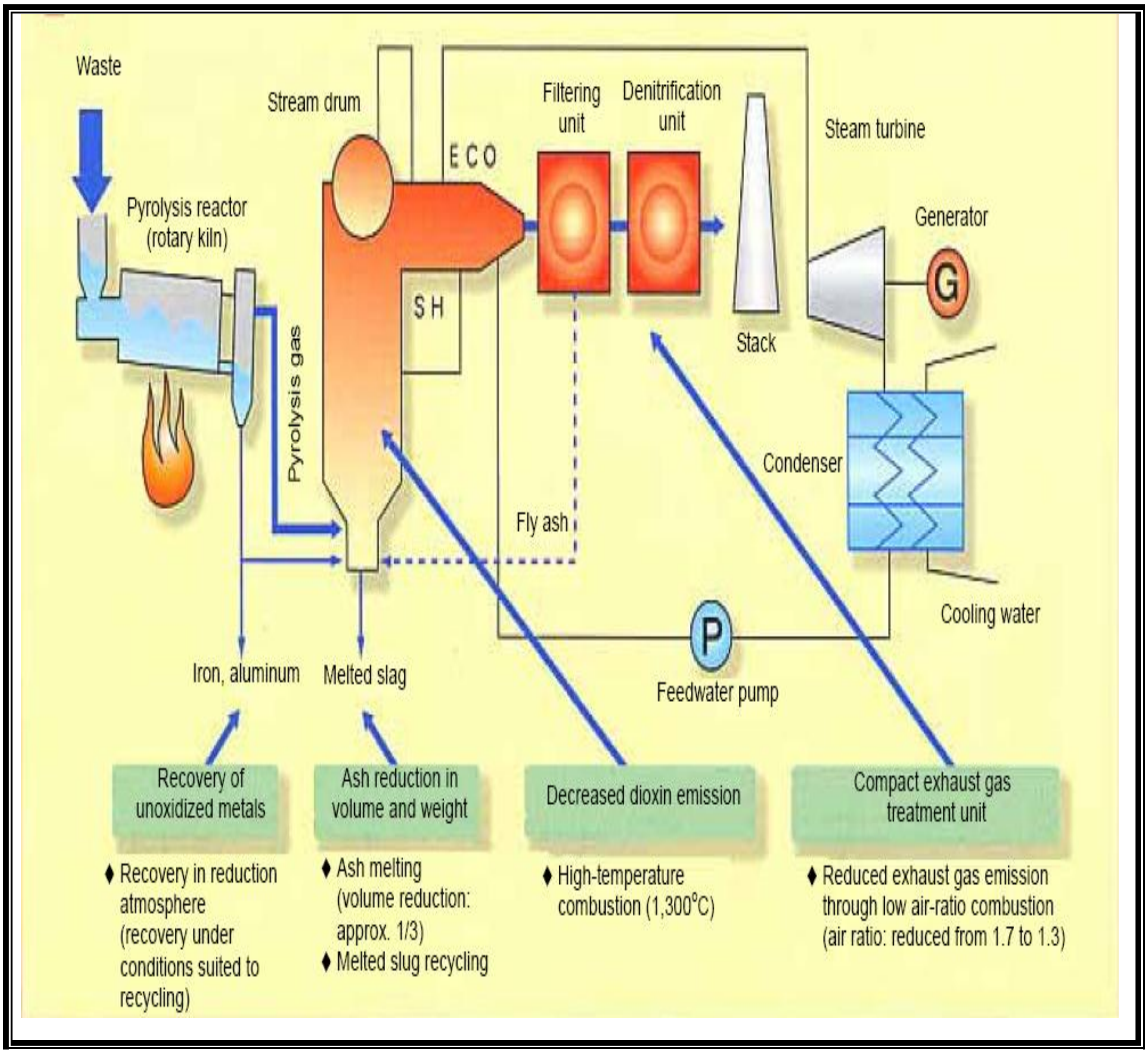


Figure 2.16: Process of Energy Recovery

2.7 PET APPLICATION AFTER RECYCLING

Sometimes recycled PET flakes are fully used or used with other new materials to reach higher quality. Generally, recycled PET flakes can be used in these materials: Fibers, A-PET sheets, bottle, and strapping. Nowadays there is high demand for PET flakes with high quality to produce the above mentioned materials in Europe, especially in Italy. The present production of flakes is not enough for this demand. Recycled PET flakes need to have special features for different usages.

2.7.1 Fiber Production Technology

For fiber production, PET pellets enter a fiber extruder machine. The extruder machine is shower-bath shaped which is installed in height with a windy channel under the shower. Materials which entered this machine are poured down towards windy channel. As it is melted, it is turned into solid by windy channel. These materials are unmonotonous fibers with low strengths. For adjustment of fibers thickness, these materials entered Unilling system where hot air stretched the fiber with monotonous speed. Therefore, the final fiber produced in this system will be with suitable thickness. At the end, a collection system is available where fibers are twisted and collected over spindles. The fiber chains have following applications:

- Clothes products, pillow, furniture filled with spinning fibers
- Cheap carpet products especially for cars
- Production of strapping, filter, inside lining and etc

2.7.2 A-PET Production Technology

In spite of excellent light features of APET, their marketing is limited because of their high production cost due to the high cost of resin. The cost of new APET is much higher than other plastics as PP and PE. The availability of PET flakes from mechanical recycling reduces its cost. It is lower than the cost of new materials. This encourages the production of APETs. Applications of APET are as follows:

Production of one-layer sheets (100% RPET)

- Internal two-layers or multi-layers inclined to a layer with new material for example a layer of PE with a layer of RPET

For the production of this sheet, complete production line consists of:

- Primary preparation of flakes, factory wastage which is produced from formed sheets, and collected wastage (approximately 30%)
- Crystallization tools for producing crystallized materials and drying dryers
- Mixtures and measuring materials
- Softening system and extrusion sheet which works as follow:

  Flat sheets of PET from extrusion process are stretched over roller where cool water is passed under. General thickness of sheets over these rollers is justified and sheets are then dried. The sheets are cut and moved to the collecting system to be twisted around the spindles. The most important usage of APET is as food package, dairy products and etc.

2.7.3 PET Bottles to PET Bottles Technology

Since PET bottles can now be reused as a PET raw material; then it implied that PET recycling is a necessity and an up-to-the-future option. PET bottles are obtained via the practice of returnable system or from collection of plastic waste. Due to the possibility of bottle-to-bottle recycling process, it is now easy to produce PET beverage containers from PET recyclate.

It is not advisable to use PET bottles as raw materials in production of soft drink bottles or liquor bottles due to unhygienic nature and associated smell. But from economic point, it is better to convert PET bottles to their state at synthesis stage rather than generality PET resin directly from petroleum. A “bottle-to-bottle” scheme as been adopted makes resin equivalent to newly made resin suitable for drinks bottles. This scheme is just a break down of the used PET bottles into their monomers (depolymerization) before turning them again into PET resin. The break down is a combination of ethylene glycol (EG) and methanol to break waste PET resin into DMT (dimethyl terephthalate) (Christel, 2000). DMT will be utilized as a raw material used to make film and textiles. Therefore this technique decomposes waste PET bottles further from DMT to PTA (purified terephthalic acid) to make PET resin (Figure 2.17).

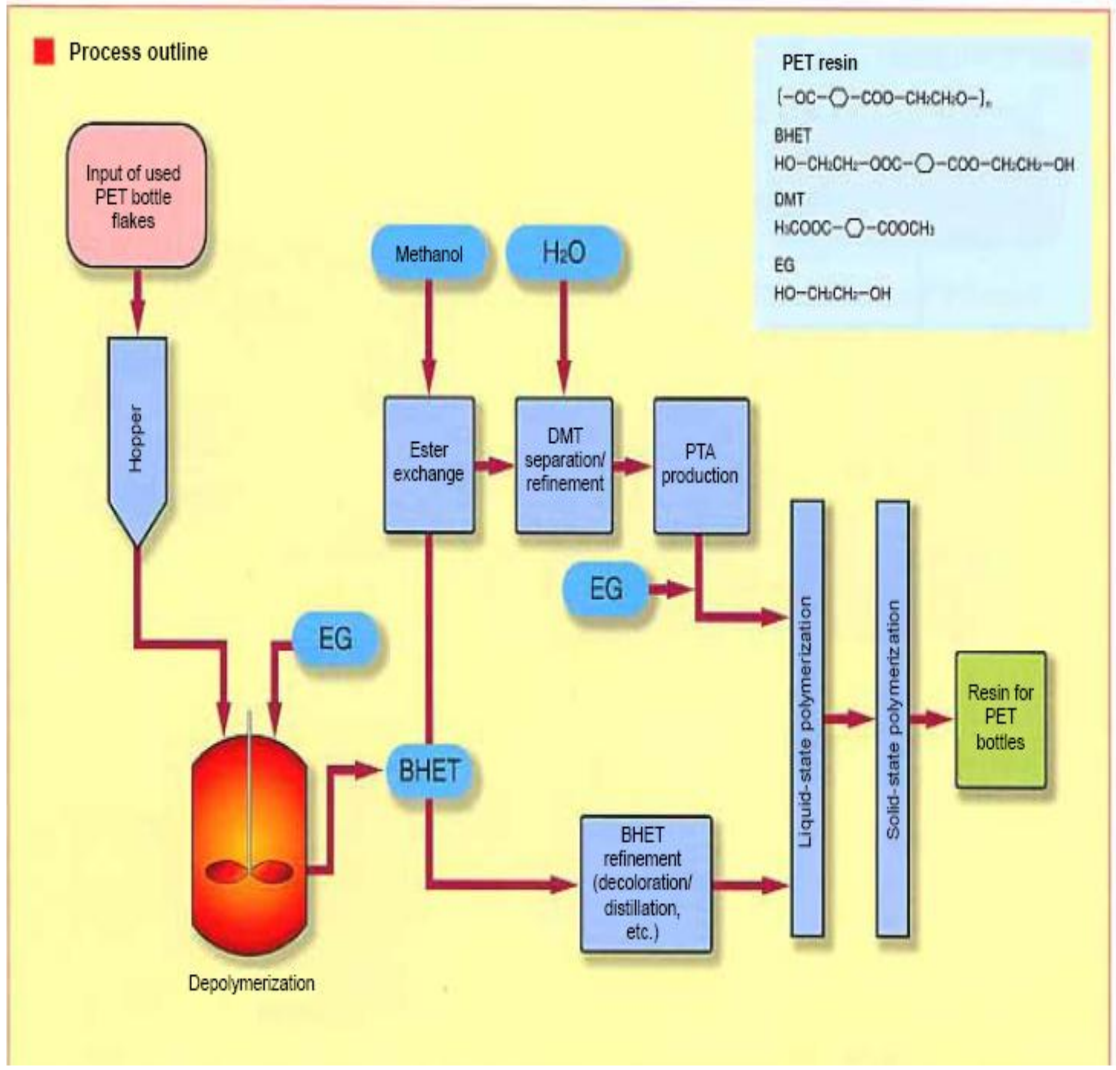


Figure2.17: PET Bottles to PET Bottles Technology

2.7.4 Strapping Production Technology

Strapping tape which has high vibration strength is made of RPET materials and it can be used in fastening different kinds of packs. Recycled flakes are not suitable because their gravity is less than usual. In most cases, regranulizing and passing of solid phase can be used to produce strapping with low to average stretch power. PET packing strap production is a new model of packing material machine. PET packing strap is the best replacement for old packing material. Nowadays, the PET packing strap has been widely used in many industries such as paper, steel, chemical fiber, cotton, and so on (Saatniya, 2002).

To produce strapping PET pellets are injected first into the extruder system, then it moves along the horizontal chamber of the extruder where water from the shower drops on the materials and initiates cooling for proper solidification. In this system the right width and thickness of materials are achieved, based on the strength and speed of the machine and its temperature. Then the belts are twisted around different spindles (Figure 2.18). Industries of plastic recycling produce new materials in following branches:

- Polyurethane foams
- Chemical resins which can be used in producing computer pieces
- Bag and shoes production
- Geotextiles production

Figure 2.18: PET Strapping Tape

2.8 ADVANTAGE AND DISADVANTAGE OF PET RECYCLING

Advantages of plastic recycling are many. One of the major advantages is the reduction in use of non renewable fossil fuels which would have been used if one wants to produce new plastic materials. Before recycling, it needs separation and sorting of PET from other plastics properly. Thus, training of waste generators will be required, so that they can separate the wastes properly. The amount of plastic (25.2%) that reaches the landfill sites is high (Yatim and Arsha, 2010). Disposal of per tonne of plastic needs 35 m^3 spaces which is 15 times more than other waste. This can be avoided by recycling and the disposed of plastic waste to landfills will be reduced by an average of 5.4% (U.S. EPA, 2000). Thus it will reduce landfill disposal fees and minimize land pollution potential. Recycling plastics help to reduce carbon emissions. Due to the higher molecular weight of the PET polymer chains, plastic recycling tend to be more expensive than recycling other materials like metal and glass. The polymer chains that bind PET does not dissociate /dissolve under heating and this is why a complex process is required. It seems that recycling small quantities of PETs may not be economical. However, it requires minimal processing equipment for PET recycling. It is not advisable to mix PET with different types of plastics because it reduces the quality of production (Pakhare , 2008).

Raw materials for producing PET are often imported from other countries. PET recycling can prevent importing of raw materials to produce PET containers. It also prevents the movement of currency out of the country. PET recycling can also create jobs and income in a society by collecting, sorting, other recycling processes, production and supplying new products. PET recycling not only saves the use of raw material i.e. oil but also conserves energy and helps to sustain the available natural resources that would have been used to produce new PET containers. PET containers have more insistence against decomposition because of their carbon-carbon chain. With PET recycling, the contamination of environment especially soil can be reduced. Burying waste can increase emission of greenhouse gases such as methane and carbon dioxide. PET recycling will prevent emission of these two greenhouse gases that causes global warming. Energy recovery from PET incineration in standard furnace can be saved in fossil fuels with heating value of 23 MJ per kg (Omrani, 2005).