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[1.] Maja RUJNIC-SOKELE, [2.] Gordana BARIC

LIFE CYCLE OF POLYETHYLENE BAG

[1-2.] University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, Zagreb, CROATIA

Abstract: Polyethylene is the most common plastic material that is used mainly for packaging purposes. One polyethylene product that has gained a lot of public interest in the recent years is single-use carrier or shopping bag. The polyethylene bag is lightweight, strong and hygienic, so it is the mostly used bag across the world. Unfortunately, polyethylene bags are the synonym of plastic waste. They are blamed for being non-degradable, for consuming valuable oil resources, for presenting the threat to marine animals, etc. Some countries have already taken some measures, which include a levy or a ban on plastic shopping bags. The paper presents the overview of polyethylene bag life cycle, from natural gas processing to its disposal and discusses main issues that undeservedly make shopping bag the biggest environmental evil of the world.
Keywords: polyethylene, plastic bags, environment

1. PRODUCTION OF POLYETHYLENE

Polyethylene was discovered in 1933 by Reginald Gibson and Eric Fawcett at the British industrial giant, Imperial Chemical Industries (ICT). Polyethylene is a polymer of ethylene, $H_2C=CH_2$, having the formula $(–CH_2\ CH_2–)_n$. It is produced at high temperatures in the presence of any of several catalysts, depending on the desired properties of the end-use product. Other structures (leading to long and short branches) may be present, depending on the procedure used in the synthesis. PE is the largest volume polymer consumed in the world, almost 78 million tons in 2012, or near 37% of all plastics. It is a versatile material that offers high performance compared to other polymers and alternative materials such as glass, metal or paper. [1, 2]

Polyethylene is derived from either modifying natural gas (a methane, ethane, propane mix) or from the catalytic cracking of crude oil into gasoline (Figure 1). In a highly purified form, it is piped directly from the refinery to a separate polymerization plant. Here, under the right conditions of temperature, pressure and catalysis, the double bond of the ethylene monomer opens up and many monomers link up to form long chains. In commercial polyethylene, the number of monomer repeat units ranges from 1,000 to 10,000 (molecular weight ranges from 28,000 to 280,000). [3]

Natural gas processing consists of separating all of the various hydrocarbons and fluids from the pure natural gas, to produce what is known as 'pipeline quality' dry natural gas. Major transportation pipelines usually impose restrictions on the make-up of the natural gas that is allowed into the pipeline. That means that before the natural gas can be transported it must be purified. So, the ethane, propane, butane, and pentanes must be removed from natural gas. These associated hydrocarbons, known as 'natural gas liquids' (NGLs) can be very valuable by-products of natural gas processing. NGLs include ethane, propane, butane, iso-butane, and natural gasoline. These NGLs are sold separately and have a variety of different uses, including enhancing oil recovery in oil wells, providing raw materials for oil refineries or petrochemical plants, and as sources of energy. [4]

Ethane is a colourless, odourless, gaseous hydrocarbon (compound of hydrogen and carbon), belonging to the paraffin series; its chemical formula is C_2H_6. Ethane is structurally the simplest hydrocarbon that contains a single carbon-carbon bond. It is the second most important constituent of natural gas; it also occurs dissolved in petroleum oils and as a by-product of oil refinery operations and of the carbonization of coal. The industrial importance of ethane is based upon the ease with which it may be converted to ethylene (C_2H_4) and hydrogen by pyrolysis, or cracking, when passed through hot tubes. Like propane and, to a lesser extent, butane, ethane is a major raw material for the huge ethylene petrochemical industry, which produces such important products as polyethylene plastic, ethylene glycol, and ethyl alcohol. [5]

Ethylene is the simplest of the organic compounds known as alkenes, which contain carbon-carbon double bonds. It is a colourless, flammable gas having a sweet taste and odour. Natural sources of ethylene include both natural gas and petroleum; it is also a naturally occurring hormone in plants, in which it inhibits growth and promotes leaf fall, and in fruits, in which it promotes ripening. [6]

Ethylene is an important industrial organic chemical. It is produced by heating either natural gas, especially its ethane and propane components, or petroleum to 800 – 900 °C, giving a mixture of gases from which the ethylene is separated. Ethylene use falls into two main categories: 1) as a monomer, from which longer carbon chains are constructed, and 2) as a starting material for other two-carbon compounds. The first of these is the single largest use of ethylene, consuming about one-half of the annual output. Polymerization of ethylene gives polyethylene; when polymerization is carried out at high pressures and temperatures, the product is called low-density polyethylene and has properties different from the high-density polyethylene formed by polymerization under Ziegler-Natta catalytic conditions. Ethylene is the starting material for the preparation of a number of two-carbon compounds including ethanol (industrial alcohol), ethylene oxide (converted to ethylene glycol for antifreeze and polyester fibres and films), acetaldehyde (converted to acetic acid), and vinyl chloride (converted to polyvinyl chloride). In addition to these compounds, ethylene and benzene combine to form ethyl benzene, which is dehydrogenated to styrene for use in the production of plastics and synthetic rubber. [6]

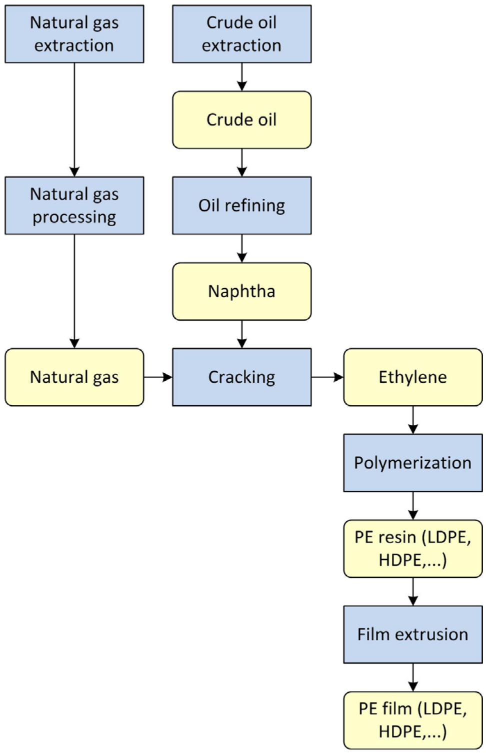

Figure 1 – Production cycle of polyethylene – from raw materials to the final product [7]

2. BASIC TYPES OF POLYETHYLENE

Polyethylene grades are mainly classified according to their density (Table 1).

Table 1 – Characteristics of different grades of PE [1]

PE	Density, g/cm³	Degree of crystallinity, %	Number of branches (per 1000 carbon atoms)
VLDPE	0.890 – 0.915	-	Numerous
LDPE	0.910 – 0.925	40 – 50	20 – 30 (methyl); 3 – 5 (n-butyl)
LLDPE	0.910 – 0.925	-	only contains short branches
MDPE	0.926 – 0.940	-	4 – 6 (formed from blending LDPE/HDPE or LLDPE copolymer)
HDPE	0.942 – 0.965	60 – 80	<4 (Phillips); 5 – 7 (Ziegler)

Low-density polyethylene (LDPE) is a semi-rigid, translucent material, and was the first of the polyethylene to be developed. Its qualities include toughness, flexibility, resistance to chemicals and weather, and low water absorption. It is easily processed by most methods and has a low cost. It is an excellent material where corrosion resistance is an important factor, but stiffness, high temperature, and structural strength are not important consideration. Ease of processing, combined with improved product performance, continues to give cost-competitive solutions to converters in a wide variety of film applications. These range from complex food packaging structures to shopping bags, coated paperboards, liners, overwraps, consumer bags, heavy-duty sacks, clarity shrink and collation films, lamination films, agricultural films, extrusion coatings, caps and closures, and a variety of durable products such as power cables and toys. [1] Some LDPE packaging products are shown in Figure 2.


a)

b)

Figure 1 – LDPE packaging, a – heavy duty sack [8], b – bottles [9]

Linear LDPE (LLDPE) is manufactured by introducing co-monomers such as 1-butene or 1-octane, which introduces short chain branches into the polymer and limits long chain branching. The linearity of the chain gives strength and the branching provides toughness, giving better properties than LDPE. [10]

The long-side branching of the LDPE molecules produces a more amorphous polymer having a lower melting point and higher clarity compared to LLDPE. LDPE is also differentiated from LLDPE by poorer physical properties as regards compared to strength, puncture and tear resistance, and elongation. LLDPE resins are ideal for down gauged lids and a variety of parts such as industrial containers, rubbish bins, automotive parts, closures, and similar items. LLDPE resins exhibit high gloss and low odour and most are suitable for packaging applications. Today, LDPE has almost totally been replaced by LLDPE. [1]

HDPE resins provide toughness, rigidity and strength for blow-moulding applications, extruded and film products, and injection moulded items. They offer an excellent combination of stiffness and environmental stress crack resistance, and have many applications in personal care, household, industrial container, and bottle products. HDPE is a flexible, translucent/waxy material. It is weatherproof, easy to process by most methods, has a low cost, and has good chemical resistance. It has a high tensile strength, four times that of LDPE, and has high compressive strength. HDPE has exceptional impact strength, being one of the best impact-resistant thermoplastics available, and has excellent machinability and self-lubricating characteristics. Its properties are maintained at extremely low temperatures. [1]

Representing the largest portion of PE applications, HDPE is stronger and stiffer than LDPE but its impact strength is not as good at low temperatures. It is also more prone to warpage due to its higher crystallinity and also has higher shrinkage than LDPE. [1]

Blow moulding applications such as bottles, packaging containers, car fuel tanks, toys, and household goods account for over 27% of world demand (Figure 2). Film and sheet uses include wrapping, refuse sacks, carrier bags, and industrial liners. Injection-moulding grades are used in crates, pallets, packaging containers, housewares, and toys. Extrusion grades are typically used in pipes, wire coating, and cable insulation. HDPE does have certain disadvantages. It is susceptible to stress cracking, has lower stiffness compared to polypropylene, high mould shrinkage, and poor

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UV resistance. It is also available in a UV-stabilised form that has better UV resistance, but the tensile strength and elongation at break are reduced compared with unmodified HDPE. [1]

a) b)

Figure 2 – HDPE products, a – drum [11], b – toy made of recycled milk bottles [12]

Medium-density polyethylene (MDPE) is normally a mixture of LDPE and HDPE and therefore has a property profile somewhere between these two materials. As with the other grades, its role has decreased significantly with the introduction of linear grades. It is used for gas pipes and fittings, sacks, shrink films, packaging film, carrier bags, and screw closures. [1]

3. ADDITIVES

The numerous and diverse applications of polyethylene would not be possible without the development of suitable additives. Additives are used for the preservation of some properties (stabilization against the action of heat, oxygen, light, and so on), to facilitate the processing of different items, and/or for the modification of some properties for special purposes. Unstabilized PE oxidises in the presence of air, rate of oxidation increasing with increasing temperature. Oxidation leads to embrittlement, surface cracking, discolouration, and loss of mechanical properties and clarity. All commercial grades of PE incorporate stabilisers that give protection against oxidation during processing and under service conditions. Also, unstabilized PE very rapidly becomes brittle when exposed (prolonged exposure) to sunlight, caused mainly by UV radiation. Degradation is accompanied by marked deterioration in mechanical properties, gloss loss, and cracking, so light stabilisers have to be are added as well. Typical additives used with PE film are listed in Table 2. [1]

Table 2 – Typical additives used with polyethylene film extrusion resins [13]

Additives	Primary benefit
Anti-static agent	Static build-up resistance
Slip/anti-block agent	Improved film to film slip and blocking
UV stabilizers	Resistance to effects of sunlight
Colour pigments	Add colour pigment concentrates to film
Carbon fillers	High concentration results in conductivity of the film
Flame retardant	Reactive compounds and additive compounds to render a polymer fire resistant

4. MANUFACTURING OF POLYETHYLENE FILM

Polyethylene film, produced by blown film extrusion, is commonly used for packaging, whether for foodstuffs or other products. At the centre of any extrusion process is the extruder screw. Figure 3 shows the blown film extrusion process. Generally pelletized polyethylene is gravity fed, from the hopper, into the feed section of the screw which is turning inside a very close fitty and stationary barrel. The resultant frictional force on the material causes it to move forward in the barrel. It heats up as it moves, both from frictional heat generation and conducted heat from the external barrel heaters. The plastic soon begins to melt – this melting continues along the screw until no more solid remains. After having travelled along the screw channel, the melt passes through a screen pack and supporting breaker plate and the adapter to the die. The screen pack serves mainly as a filter for foreign matter that may have found its way into the hopper. The melt is then forced through the die adopting the shape of the flow channel (i.e. a circular tube for blown film). The tubular profile from the blown film die is held in tubular form by internal air pressure and is generally externally air cooled with an air ring. The cooled bubble is collapsed at the nip rollers, slit to separate the two halves of the bubble and the resultant two sheets are wound up as rolls (Figure 3). The film sheet can then be converted into bags, pouches, etc. as required. The thickness of the film produced tends to be from 20 – 200 μm. [3]

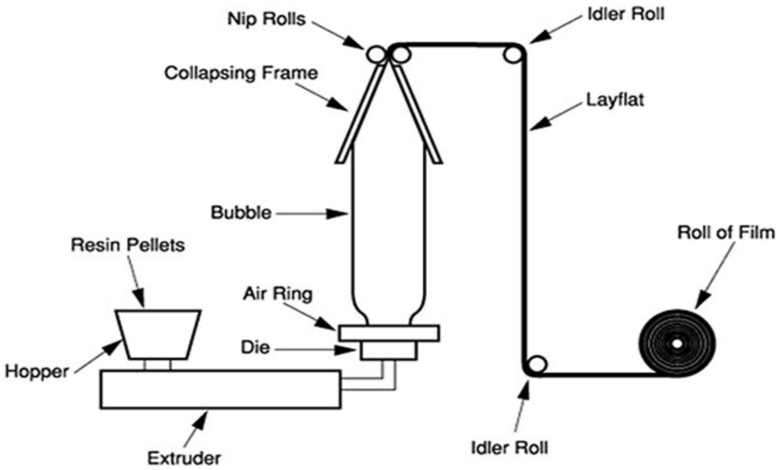

Figure 3 – Basic blown film extrusion line [14]

All PE grades are commonly used as materials for blown film extrusion. Heavy-duty films are often in the range of 0.1 – 0.2 mm and can be thick as 0.5 mm. They are used for agricultural, construction, and industrial applications, including covers for silage, greenhouses, chemical/solar ponds, or liners for reservoirs, ponds, pits, and ditches and are often associated with irrigation. Packaging and agricultural mulch film applications are also increasingly used. Multilayer coextruded extruded blown films, which contain from 3 to 11 layers, are increasingly used for barrier packaging. Extruded blown films can produce a moderate amount of heat-induced contraction (about 50%) and thus find applications as shrink films. [1]

5. RECOVERY OPTIONS

Three options are available for recovery of polyethylene: mechanical recycling, chemical recycling, and energy recovery. Mechanical recycling uses physical means such as grinding, heating, end extruding to process polyethylene waste into new products. Chemical recycling uses chemical process to convert plastic waste into useful products, such as monomers for new plastics, fuels, or basic chemicals for general chemical production. The third option, energy recovery, generates heat or electricity (or both) whether by direct incineration in municipal incinerators, or by replacing other fuels in blast furnaces, cement kilns, or power stations. [1]

Because of the ease of processing, most products made of PE can be reprocessed to other products. Recycled products made from HDPE include detergent and engine oil bottles, dustbins, soft drink bottle crates, drainage pipes, animal pens, drums, matting, milk bottle carriers, industrial pallets, plastic lumber, traffic barrier cones, flower pots, golf bag liners, kitchen drain boards, and hair combs. Recycled LDPE can be used to make most of the products made from virgin LDPE, except for packaging. [1]

Polyethylene can be readily thermally decomposed to gaseous and liquid hydrocarbons. Polyethylene wastes have a high calorific value of 36 to 46 MJ/kg, hence they give an important contribution to reducing the energetic needs in the production of hot water, steam and electricity. [1]

6. POLYETHYLENE BAGS *ISSUE*

A plastic shopping bag is a polymer carry bag provided or utilised at the retail point of sale for carrying and transporting retail goods and which is only intended for one way use. This includes all single use plastic retail bags, but excludes produce bags used in-store, dry cleaning bags, garbage bags and other primary product packaging. [15]

Because of their light weight, plastic bags only constitute a tiny percentage of the overall waste stream (less than 1%) but they tend to be in the spotlight because they are an icon of modern convenience culture and lifestyles. Plastic bags are popular with consumers and retailers because of all the practical advantages they offer; they are light, cheap, strong, and a hygienic way to transport food and products home.

Views on the environmental impact of plastic bag consumption vary greatly. Whereas some consider that they are just a nuisance, others believe they are a real hazard that should be banned. This is also reflected in the variety of instruments used to tackle the plastic bag issue, and the measures include bans on plastic bags, taxations or charges, promotion of other types of bags (biodegradable, paper, cloth, etc...), as well as awareness raising campaigns.

The main arguments against plastic bags are linked to the littering issue in some countries as well as the persistence in landfill. Some argue that they are hazardous to wildlife (especially marine), potentially entangling animals or being mistaken for food. And finally the environmental impact linked to the consumption of raw materials and the production process is also pointed at.

Litter is a result of articles being disposed of inappropriately, either due to inadequate waste management infrastructures or to the irresponsible behaviour of citizens. It is not caused by plastics and will not be eliminated by banning plastic bags. The public has to be educated in order to acknowledge the necessity to dispose of plastic and any other product in a responsible manner.

The widely stated accusation that the bags kill 100,000 animals and a million seabirds every year is false; in fact, they pose only a minimal threat to most marine species, including seals, whales, dolphins and seabirds. Most deaths are caused when creatures became caught up in entanglements, such as fishing gear, ropes, lines and strapping bands. Even though the photograph of a turtle eating a plastic bag is published thousands of times on the Internet (Figure 4a), turtles usually become entangled in gillnets, pound nets, and the lines associated with longline and trap/pot fishing gear (Figure 4b) and not in the plastic bags. [16]


a) b)

Figure 2 – Turtles and plastics, a – famous turtle eating a plastic bag [17],
b – turtle entangled in fishing net [18]

Clearly, plastic goods, as well as other consumer goods, do not belong into the ocean. Waste is too valuable to be littered into the environment. Nevertheless, marine debris is made up of all kinds of materials, so banning or taxing one material (such as plastics) will not solve the marine debris problem; it will merely shift it from one littered material to another.

What are the alternatives? For instance, consumers can choose paper, cloth or biodegradable plastic bags instead of polyethylene bags. But, despite of the general opinion, polyethylene is still the best solution for the manufacturing of shopping bags. Paper bag production has more negative environmental impacts related to air emissions, water emissions and solid waste than plastic grocery bags, so they're not a solution. Virtually nothing – not paper, food, plastic or even compostable or biodegradable products – decompose in today's landfills, because they are actually designed to be as stable and dry as possible.

For example, study of the UK Environment Agency [18] found out that the whatever type of bag is used (lightweight HDPE bag, biodegradable plastic bag, paper bag, 'bag for life' made from LDPE, heavier more durable bag polypropylene (PP) bag, or a cotton bag), the key to reducing the impacts is to reuse it as many times as possible and where reuse for shopping is not practicable, other reuse, e.g. to replace bin liners, is beneficial. The reuse of conventional HDPE and other lightweight carrier bags for shopping and/or as bin-liners is pivotal to their environmental performance and reuse as bin liners produces greater benefits than recycling bags. Also, study found that biodegradable bags have a higher global warming potential and abiotic depletion than conventional polymer bags, due both to the increased weight of material in a bag and higher material production impacts. The paper, LDPE, non-woven PP and cotton bags should be reused at least 3, 4, 11 and 131 times respectively to ensure that they have lower global warming potential than conventional HDPE carrier bags that are not reused.

While biodegradable plastic shopping bags might seem like a good idea, there are a number of problems associated with them. Biodegradable and compostable bags certified according to the internationally recognised standard EN 13432 should be recovered in industrial composting facilities because they require specific conditions (temperature, moisture, and microorganisms) for biodegradation to start. Also, using biodegradable shopping bags may promote littering as people think the bags will break down in the environment no matter how they are disposed of. But the conditions necessary for the biodegradation are seldom present in the environment, so until biodegradable products actually break down they still pose the same danger as non-biodegradable plastic bags, i.e. potential to harm wildlife and create litter problems.

The argument of using up raw materials (natural gas and crude oil) for the production of plastics is also not valid, since plastics production accounts for just 4% of oil and gas use. Other non-energy use consumes a further 4%, the chemical and petrochemical industries consume around 5%. Heating, electricity and energy production consumes a further 42%, and transport consumes 45% of our oil and gas. [19]

7. CONCLUSION

In recent years, a growing number of countries in the world have taken certain steps to reduce the number of plastic bags. Unfortunately, plastic bags have become a symbol of today's consumer culture, and the focus of the public is not aimed at the irresponsible throw-away behaviour of consumers, but at the material of which they are commonly made, polyethylene. Thin HDPE bags are particularly an eyesore, because they are very easily blown away in the wind (even when dropped in the waste bin) and usually end up in the environment, where they are highly visible. Every bag in some way affects the environment. But, as it turned out, the conventional HDPE bag has the lowest environmental impacts of most impact categories, so it is still the *greenest* option for carrying groceries home from the store, even if used just once.

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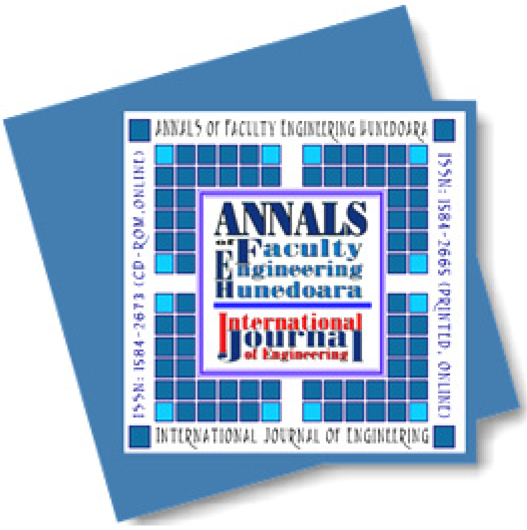

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