Life Cycle Inventory of the Manufacture of *High Density Polyethylene (HDPE)*

The Chemistry of Polyethylene

Polyethylene is a thermoplastic resin that is produced by polymerizing ethylene. It is one of the simplest polymers and comes in several forms.

Depending on the polymerization reaction, the polymer chains can be highly highly linear, or they can have side chains. The length and structure of these side chains is important in terms of the resin's commercial use because it affects the physical characteristics of the polymer.

For example, linear chains, those with few side branches, and those chains having very short branches allow the polymer molecules in the solid state to pack closely. As a result, these types of chains produce a highly crystalline polymer that has excellent mechanical properties. Chains having many branches inhibit close packing in the solid state. They produce low-density polymers with high amorphous content.

Commercially available polyethylenes can be divided into three main categories that relate to their structure: low density polyethylene, high density polyethylene, and linear low density polyethylene.

- *Low density polyethylene (LDPE),* produced in a high pressure process, contains many long side branches.
- *High density polyethylene (HDPE),* produced in a low pressure process, contains fewer side branches.
- *Linear low density polyethylene (LLDPE),* contains a large number of side branches but they are very short. As a result, the polymer is able to pack well in the solid state.

High density polyethylene which has densities ranging from 0.945 to 0.965, can be further divided into two categories:

- Higher molecular weight resins with broad molecular weight distributions that are used for blow moulding, pipe, and film packaging.
- Lower molecular weight resins with narrow molecular weight distributions that are used for injection moulding and rotational moulding.

The Characteristics of HDPE

- Stiffness
- Impact resistance
- Translucence
- Moderate barrier to gas
- Barrier to liquid
- Chemical resistance
- Electrical insulator

Typical Applications for HDPE

- Grocery bags
- Milk jugs and bottles
- Cable insulation
- Large drums
- Shipping containers
- Seating
- Rigid toys

The Manufacture of HDPE

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then "cracked" in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Ethylene olefins are homo- or co-polymerized with other comonomers to produce high density polyethylene resin. The polymerization takes place with the use of catalysts in gas-phase, solution or slurry processes. The polymer is then extruded, pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.

Life Cycle Inventory of the Manufacture of *Low Density Polyethylene (LDPE)*

The Chemistry of Polyethylene

Polyethylene is a thermoplastic resin that is produced by polymerizing ethylene. It is one of the simplest polymers and comes in several forms.

Depending on the polymerization reaction, the polymer chains can be highly highly linear, or they can have side chains. The length and structure of these side chains is important in terms of the resin's commercial use because it affects the physical characteristics of the polymer.

For example, linear chains, those with few side branches, and those chains having very short branches allow the polymer molecules in the solid state to pack closely. As a result, these types of chains produce a highly crystalline polymer that has excellent mechanical properties. Chains having many branches inhibit close packing in the solid state. They produce low-density polymers with high amorphous content.

Commercially available polyethylenes can be divided into three main categories that relate to their structure: low density polyethylene, high density polyethylene, and linear low density polyethylene.

- *Low density polyethylene (LDPE),* produced in a high pressure process, contains many long side branches.
- *High density polyethylene (HDPE),* produced in a low pressure process, contains fewer side branches.
- *Linear low density polyethylene (LLDPE),* contains a large number of side branches but they are very short. As a result, the polymer is able to pack well in the solid state.

High density polyethylene which has densities ranging from 0.945 to 0.965, can be further divided into two categories:

- Higher molecular weight resins with broad molecular weight distributions that are used for blow moulding, pipe, and film packaging.
- Lower molecular weight resins with narrow molecular weight distributions that are used for injection moulding and rotational moulding.

The Characteristics of LDPE

- Impact resistance
- Flexibility
- Moderate barrier to gas
- Barrier to liquid
- Chemical resistance
- Electrical insulator
- Low melt temperature
- Ease of processing

Typical Applications for LDPE

- Packaging film
- Grocery and garbage bags
- Lids, toys, housewares
- Stretch film and pallet wrap
- Wire and cable coatings

The Manufacture of LDPE

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then "cracked" in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Ethylene olefins are homo- or co-polymerized with other comonomers to produce high density polyethylene resin. The polymerization takes place with the use of catalysts in a very high pressure autoclave or tubular process. The polymer is then extruded, pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.

Life Cycle Inventory of the Manufacture of *Linear Low Density Polyethylene (LLDPE)*

The Chemistry of Polyethylene

Polyethylene is a thermoplastic resin that is produced by polymerizing ethylene. It is one of the simplest polymers and comes in several forms.

Depending on the polymerization reaction, the polymer chains can be highly highly linear, or they can have side chains. The length and structure of these side chains is important in terms of the resin's commercial use because it affects the physical characteristics of the polymer.

For example, linear chains, those with few side branches, and those chains having very short branches allow the polymer molecules in the solid state to pack closely. As a result, these types of chains produce a highly crystalline polymer that has excellent mechanical properties. Chains having many branches inhibit close packing in the solid state. They produce low-density polymers with high amorphous content.

Commercially available polyethylenes can be divided into three main categories that relate to their structure: low density polyethylene, high density polyethylene, and linear low density polyethylene.

- *Low density polyethylene (LDPE),* produced in a high pressure process, contains many long side branches.
- *High density polyethylene (HDPE),* produced in a low pressure process, contains fewer side branches.
- *Linear low density polyethylene (LLDPE),* contains a large number of side branches but they are very short. As a result, the polymer is able to pack well in the solid state.

High density polyethylene which has densities ranging from 0.945 to 0.965, can be further divided into two categories:

- Higher molecular weight resins with broad molecular weight distributions that are used for blow moulding, pipe, and film packaging.
- Lower molecular weight resins with narrow molecular weight distributions that are used for injection moulding and rotational moulding.

The Characteristics of LLDPE

- Impact resistance
- Flexibility
- Barrier to gas (low)
- Barrier to liquid
- Chemical resistance
- Electrical insulator
- Low melt temperature
- Ease of processing

Typical Applications for LLDPE

- Geomembranes
- Grocery and garbage bags
- Flexible pipe
- Stretch film and pallet wrap
- Wire and cable coatings

The Manufacture of LLDPE

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then "cracked" in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Ethylene olefins are co-polymerized with butene, hexene and/or octene to produce a linear polyethylene resin, LLDPE. The polymerization occurs with a catalyst in the gas or solution phase. The polymer is then extruded, pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.

Life Cycle Inventory of the Manufacture of *Polypropylene (PP)*

The Chemistry of Polypropylene

Polypropylene is a thermoplastic resin that is produced by polymerizing propylene. It is chemically one of the simplest polymers.

Three basic chemical structures/types of polypropylene exist: isotactic, syndiotactic and atactic.

- When the CH_3 side groups lie on one side of the polymer chain, the polymer is said to be an isotactic polypropylene.
- When the CH_3 side groups lie on alternate sides of the chain, the polymer is said to be a syndiotactic polypropolylene.
- When the CH_3 side groups are distributed randomly on either side of the chain, the polymer is said to be atactic.

The arrangement of the resin's CH_3 side groups affects the characteristics of the polymer and, therefore, the applications to which the resin is best suited.

Isotactic and syndiotactic polypropylene can be packed in the solid state, forming a semi-crystalline polymer with good mechanical properties. Isotactic polypropylene's ordered molecular structure makes it stiff enough for a wide range of uses. Because of its versatility, resin producers tend to maximize the production of the isotactic form.

Commercial polypropylene has three different forms; homopolymers, copolymers and random copolymers each serving different applications.

The Characteristics of PP

- Stiffness
- Impact resistance
- Flexibility (in film grades)
- Clarity (in select grades)
- Moderate barrier to gas
- Barrier to liquid
- Chemical resistance
- High melt temperature

Typical Applications for PP

- Bottles, rigid packaging
- Film
- Carpets
- Diaper cover stock
- Battery cases
- Caps and closures
- Automotive parts
- Outdoor furniture
- Medical equipment
- Food packaging
- Housewares

The Manufacture of PP

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then "cracked" in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Propylene olefins are either homo or co-polymerized with comonomers to produce polypropylene resin. The polymerization takes place with the use of catalysts in bulk, gas-phase or slurry processes. The polymer is then extruded, pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.

Life Cycle Inventory of the Manufacture of *General Purpose Polystyrene (GPPS)*

The Chemistry of Polystyrene

Polystyrene is a versatile polymer resin that is used in a wide range of applications, especially in the packaging industry. It is sold in three main forms: crystal, or general purpose polymer, high impact resin and expandable resin.

- The crystal form, otherwise known as general purpose polystyrene or GPPS, is pure polystyrene with few additives. It is used when clarity is required, but it is relatively brittle.
- The high impact form of this resin is translucent or opaque. Rubber compounds incorporated in the resin inhibit crack propagation and reduce the characteristic brittleness of pure GPPS.
- In the expandable form, two distinct variations exist.
    - In the EPS (expandable polystyrene) variation, which is used primarily for cups, moulded parts and packaging, the most common blowing agent is isopentane. The blowing agent is incorporated into the resin prior to final foam manufacture.
    - In the foamed sheet variation, the blowing agents are much more diversified, i.e. isopentane, n-pentane, isobutane, n-butane, hydrochlorofluorocarbons (HCFC's) and CO_2. The blowing agent is added to foam the polystyrene in the extrusion process.

Although general purpose polystyrene is often called *crystalline polystyrene*, this name refers to its transparency as opposed to its molecular structure. GPPS, the parent of the family of styrenic plastics, is a linear polymer. It has low density and high molecular weight.

Three basic grades of GPPS exist: high-flow, medium-flow and high-heat.

The Characteristics of GPPS

- Stiffness (brittle)
- Clarity
- Barrier to liquid
- Thermal insulator (in foamed applications)
- Ease of processing

Typical Applications for GPPS

- Disposable medical wares
- Dinnerware
- Toys
- Packaging
- Tumblers
- Extruded foam and sheet
- Thermoformed lighting and decorative fixtures
- Compact disc "jewel" boxes
- Video cassettes

The Manufacture of GPPS

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then "cracked" in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Ethylene and benzene are reacted in gas or liquid phase to produce ethylbenzene, which is dehydrogenated in a separate process to produce styrene.

Styrene monomer is polymerized by the addition of a free radical and heat in either bulk or solution processes. A catalyst is used in some cases. Various additives are used for control of molecular weight, flow properties, resin colour, mould release, thermal stability, etc. The polymer is then extruded, pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.

Life Cycle Inventory of the Manufacture of *High Impact Polystyrene (HIPS)*

The Chemistry of Polystyrene

Polystyrene is a versatile polymer resin that is used in a wide range of applications, especially in the packaging industry. It is sold in three main forms: crystal, or general purpose polymer, high impact resin and expandable resin.

- The crystal form, otherwise known as general purpose polystyrene or GPPS, is pure polystyrene with few additives. It is used when clarity is required, but it is relatively brittle.
- The high impact form of this resin is translucent or opaque. Rubber compounds incorporated in the resin inhibit crack propagation and reduce the characteristic brittleness of pure GPPS.
- In the expandable form, two distinct variations exist.
  - In the EPS (expandable polystyrene) variation, which is used primarily for cups, moulded parts and packaging, the most common blowing agent is isopentane. The blowing agent is incorporated into the resin prior to final foam manufacture.
  - In the foamed sheet variation, the blowing agents are much more diversified, i.e. isopentane, n-pentane, isobutane, n-butane, hydrochlorofluorocarbons (HCFC's) and CO_2. The blowing agent is added to foam the polystyrene in the extrusion process.

The Characteristics of HIPS

- Stiffness
- Impact resistance
- Translucence
- Barrier to liquid
- Ease of processing

Typical Applications for HIPS

- Reusable foodservice ware for airline use
- Disposable razors
- Pens
- Housings for electronics

The Manufacture of HIPS

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then "cracked" in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Ethylene and benzene are reacted in gas or liquid phase to produce ethylbenzene, which is dehydrogenated in a separate process to produce styrene.

Styrene monomer and rubber are polymerized by the addition of a free radical and heat in either bulk or solution processes. A catalyst is used in some cases. Various additives are used for control of molecular weight, flow properties, resin colour, mould release, thermal stability, etc. The polymer is then extruded, pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.

Life Cycle Inventory of the Manufacture of *Polyethylene Terephthalate (PET)*

The Chemistry of Polyethylene Terephthalate

Polyethylene terephthalate (PET) is a thermoplastic resin produced by the polymerization of pure terephthalic acid or dimethylterephthalate with ethylene glycol.

PET resin is available in either amorphous or crystalline forms. Most engineering grades of PET are crystalline.

The Characteristics of PET

- Stiffness
- Impact resistance
- Clarity
- Good barrier to gas
- Barrier to liquid
- Chemical resistance
- Fatigue resistance
- Creep resistance
- High melt temperature

Typical Applications for PET

- Fibres
- Bottles
- Packaging
- Strapping
- Monofilament
- Recording tapes

The Manufacture of PET

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then “cracked” in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Ethylene is reacted with air or oxygen, mixed with water, and then stripped to recover ethylene oxide. The ethylene oxide is then hydrated with water to produce ethylene glycol, one of the process components in the manufacture of PET.

Liquid phase catalytic oxidation of paraxylene yields crude terephthalic acid (TPA), which in turn is used to produce two separate compounds used in PET production. When crude TPA is crystallized from solution, re-dissolved under pressure and heat and catalytically hydrogenated, the cooled solution yields pure terephthalic acid (PTA). When crude TPA is crystallized from solution and reacted with methanol at moderate temperature and pressure, dimethylterephthalate (DMT) is recovered by re-crystallization.

PTA and/or DMT is reacted with ethylene glycol to produce bishydroxyethyl terephthalate , which is polymerized in the liquid phase into amorphous PET. Amorphous PET is further polymerized in the solid state to yield a partially crystalline PET suitable for use in the production of bottles. The polymer is pelletized and stored for packaging or bulk shipment to a fabricator of plastics.

Life Cycle Inventory of the Manufacture of *Polyvinyl Chloride (PVC)*

The Chemistry of PVC

Polyvinyl chloride, a thermoplastic resin, is a chlorinated hydrocarbon polymer. Its structure is similar to that of polyethylene, with an exception. The alternate carbon atoms in the main chain have one of their hydrogen atoms replaced by a chlorine atom.

The pure polymer of polyvinyl chloride is hard, brittle, and difficult to process. By adding plasticizers, fillers and pigments, it becomes flexible. As a result of these additives, PVC is now one of the most versatile and highly used commercial thermoplastics.

The many applications of PVC can be divided into two types:

- ➢ Rigid products which have little or no plasticizer added
- ➢ Flexible products with varing amounts of plasticizer

The Characteristics of PVC

- Stiffness
- Impact resistance
- Flexibility
- Clarity
- Low barrier to gas
- Barrier to liquid
- Chemical resistance
- Electrical insulator
- Resistance to ultra violet light
- Flame resistance

Typical Applications for PVC

- Pipe
- Siding
- Doors and windows
- Resilient flooring
- Wire and cable insulation
- Automotive fabrics
- Food wrap
- Bottles
- Medical tubing
- Blood and IV solution bags
- Toys
- Garden hose
- Geomembrane liners

The Manufacture of PVC

The primary sources of the hydrocarbons used in polymer production in Canada are crude oil and natural gas. Both are extracted from the ground and processed (refined) to recover desired components or fractions.

The refined hydrocarbon outputs, naphtha, ethane, propane, etc. are then “cracked” in a thermal process to produce olefins, such as ethylene or propylene, aromatics and/or fuel. Plant configurations vary widely based on the product mix desired and feedstock used. Many cracking facilities are integrated with the downstream processing of co-products. Some are also integrated with upstream oil refining and gas processing.

Chlorine, the other key component of PVC, is produced by the electrolysis of an aqueous solution of sodium chloride or potassium chloride. During electrolysis, sodium hydroxide and hydrogen are produced as co-products. In some plants sodium hypochlorite and hydrogen chloride also are produced. Sodium chloride is extracted from the earth by brine pumping or salt mining.

Vinyl chloride monomer (VCM) is produced in two steps. First, 1,2 dichloroethane (EDC), is produced by two process routes. Ethylene may be directly chlorinated with chlorine, or hydrogen chloride may be reacted with ethylene in the presence of oxygen. The EDC is then decomposed to VCM at high temperature in a pyrolysis process.

VCM is polymerized to PVC by aqueous suspension polymerization or by aqueous emulsion polymerization in the presence of a catalyst and process aids. Unpolymerized monomer is recovered. PVC is pelletized and stored for packaging or bulk shipment to a fabricator of plastic products.