Kirk Cantor

Bonus companion software included

Blown Film Extrusion

HANSER

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3rd Edition

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Preface

Blown film extrusion is one of the most significant polymer processing methods. Several billion pounds of polymer, mostly polyethylene, are processed annually by this technique. While some applications for blown film are quite complex, such as scientific balloons (Figure 1), the majority of products manufactured on blown film equipment are used in commodity applications with low profit margins: grocery sacks, garbage bags, and flexible packaging (Figure 2). Consequently, sophisticated hardware, materials, and processing methods have been developed to yield film at very high output rates exhibiting both low dimensional variation and consistent solid-state properties.

Figure 1 A high altitude, scientific balloon being prepared for launch *(National Aeronautics and Space Administration)*

Figure 2 Blown film extrusion is used to produce very high volumes of commodity products such as grocery and produce bags

Polymer chemistry and molecular structure are vital in establishing film properties, but bubble geometry resulting from processing conditions is also significant. Molecular orientation and crystalline structure – controlled by bubble dimensions – affect properties such as tensile strength, impact toughness, and clarity.

As a manufacturing process, blown film is somewhat unique, even compared with other extrusion processes. Molten polymer generally exits the die vertically in the form of a freely extruded bubble reaching heights of 50 feet (15 meters) or more (Figure 3). Guides surrounding the bubble may limit its mobility, but it is still quite exposed to dimensional variation compared to the fixed extrudate in most other extrusion processes, which use vacuum sizers, calibrators, rollers, or other techniques. Depending on processing conditions, the blown film bubble has a shape freedom that allows almost any number of profiles within a designed range. Operators must have a relatively high skill level to accurately obtain the required bubble geometry (i.e., the shape resulting in specified product dimensions and properties).

The strong interdependence of process variables is another aspect of the process that requires a high level of operator skill and has led to extensive advancements in measurement and control techniques. There are many process variables – screw speed, nip speed, internal bubble air volume, and cooling rate (frost line height) – that influence bubble geometry and, as a result, film properties. An adjustment to any one of these variables leads to a change in several geometric characteristics of the bubble. For example, an operator may intend to only decrease film thickness by increasing the nip speed; however, if no other control is modified, this adjustment will also create an increase in both frost line height and layflat width. Therefore, the proficient operator is aware of the influence of each process variable on all geometric characteristics of the bubble and can control more than one characteristic at a time.

Figure 3 A blown film extrusion line *(Windmoeller & Hoelscher)*

From hardware and materials through processing and properties, this book is intended to provide the reader with a comprehensive understanding of blown film extrusion through a useful balance of theory and practice. Included in this book are the answers to why effects occur the way that they do in the blown film process, so the reader can improve his/her ability to troubleshoot and improve systems. At the same time, current practices and equipment are emphasized to keep readers up-to-date with the most productive and efficient technology.

The companion computer-based learning tool, *The Blown Film Extrusion Simulator*[1], enhances the reader's understanding. This software was developed specifically to teach blown film extrusion equipment operation and processing principles. The realistic graphic interface and intuitive operating techniques were designed to emulate actual processing methods, so learners can quickly move from the simulator to real production equipment. Throughout this book there are exercises (identified with the symbol) using the simulator to complement the methods and principles explained. It is intended that, when convenient, readers will take a break from reading the book and spend a few minutes with the simulator to enhance their understanding of the content. Before continuing to the next chapter, the reader may want to skip to Appendix 1 in Chapter 9 to learn how to download, install, and operate the simulator.

[1] Available for download using the code given in Appendix 1 at *https://plus.hanser-fachbuch.de/en*.

Contents

1 Materials for Blown Film

This chapter covers the various materials extruded by the blown film process. It is divided into two broad categories: polymers and additives. Many types of polymers are extruded into blown film, but various grades of polyethylene comprise the vast majority. Additives are used in most operations to provide performance, appearance, processing, or cost benefits.

1.1 Polymers

The desired property set for any product determines the best material for the application. The most important properties, such as physical, mechanical, optical, thermal, and electrical, provide fitness-for-use in the final product. In addition to final product (solid–state) properties, processing properties are also very important in material selection. Ease of processing in blown film can be described by characteristics such as good thermal stability, high melt strength (outside of the die), reasonable head pressures, and no melt fracture (film surface imperfections). Finally, minimal cost is a key property.

There are numerous applications for blown film, but a very high percentage of film is used in commodity applications, such as packaging and bags. These products require a combination of performance, processing, and cost that make polyethylene (PE) the ideal polymer for most applications. It is lightweight, water-resistant, has a good balance of strength and flexibility, and can provide some clarity. PE is easy to extrude and heat-seal and, perhaps most importantly, it is low-cost. In addition to these general properties of PE, it is a polymer that is very well understood scientifically, allowing for polymerization techniques that can be designed and controlled to yield specific property values over a very wide range. That is, PE grades that are much stronger than average, or much clearer, or much more flexible, can be produced.

Within the broad family of polyethylene, there are several types that find application in blown film. There are, however, other polymers used as well. While a few of these others are used in monolayer specialty films, they are mostly used as part of coextruded multilayer films, where multiple extruders feed a single die that combines the various feed streams into a single, multilayer film. The following sections detail the many polymer types used in blown film extrusion.

1.1.1 Polyethylene (PE)

Polyethylene (PE) is the simplest polymer from a chemical standpoint. It is polymerized from ethylene monomer and consists of a carbon chain backbone with two hydrogen atoms bonded to each carbon atom (Figure 1.1). Individual molecules, or chains, may reach lengths of hundreds to tens of thousands of carbon atoms. PE chains may be very linear or may be branched, depending on how the polymer was synthesized. There are many synthesis techniques for polyethylene [1].

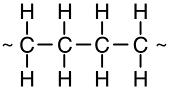

Figure 1.1 A short section of a polyethylene molecule

Blown film processing methods for PE vary somewhat depending on the grade. Differences will be discussed in the following sections. However, one important similarity is that all PE grades have a high value of specific heat. Specific heat is a measure of the energy required to raise a unit mass of material one degree in temperature. If a polymer has a high value of specific heat, this means that heat removal from the melt is relatively slow. PE has a specific heat of approximately 2 kJ/kg·K compared to approximately 1 kJ/kg·K for most other polymers. This is the reason why cooling towers for blown film polyethylene are very tall. It takes time to remove enough heat from the two layers passing through the nip rollers to prevent them from sticking together (sometimes called blocking).

1.1.1.1 Low Density Polyethylene (LDPE)

Polyethylene is often categorized by its density, a measure of the mass per unit volume (e.g., g/cm^3 or lb/in^3). When any type of polymer cools from the melt state, some of the chain sections may organize into highly ordered, more dense crystalline regions (Figure 1.2). This will occur with sections of molecules possessing long, repeating patterns. In sections containing irregular patterns, such as branch points or chain ends, crystallization does not occur and these regions are called amorphous (disordered). All PEs generally crystallize to some degree. Some polymers, such as commercial polystyrene, are completely amorphous due to hindrance of the entire molecular structure to crystallization.

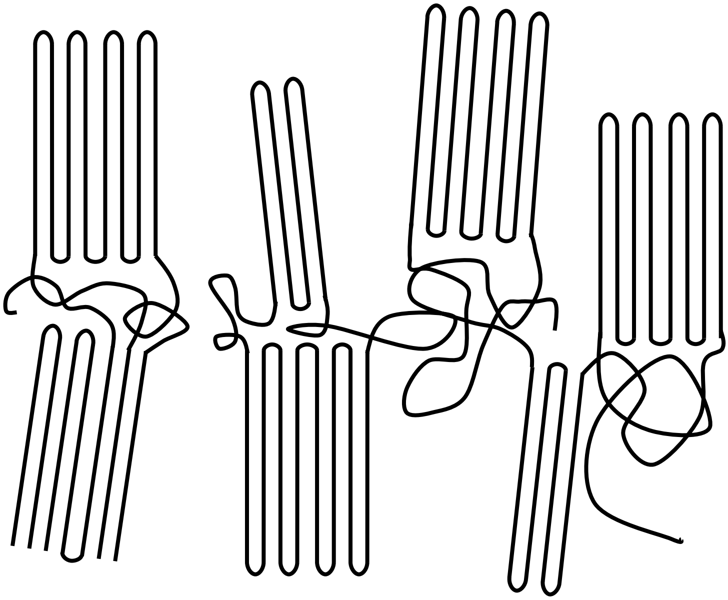

Figure 1.2 Polymer molecules are shown here in ordered, crystalline regions and disordered, amorphous regions

Low density polyethylene (LDPE) is synthesized in such a way that a highly branched polymer is formed. It consists of short chain branches (less than six carbon atoms long) and long chain branches (almost as long as the length of the backbone). Branch points along the chain serve as disruptions to the order of the system and prevent local crystallization. The lower level of crystallinity results in lower density. LDPE is generally in the density range of 0.910 to 0.925 g/cm^3.

LDPE tends to be relatively easy to process. Compared to other PE grades, it melts at a relatively low temperature (220 to 240 °F, 105 to 115 °C) and does not require as much extruder motor power. LDPE blown film grades are moderately high in viscosity, but the wide range of branching yields a fairly wide processing window and high melt strength in the bubble. This leads to a stable bubble that can be run with a low frost line height (pocket bubble, or bowl or pear shape, Figure 1.3). LDPE heat-seals very easily.

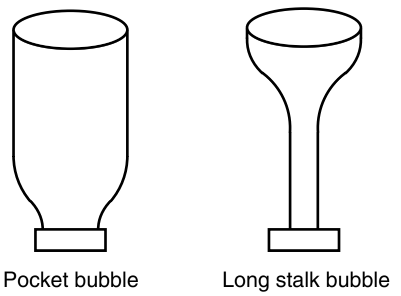

Figure 1.3 Two types of blown film bubbles

The properties of LDPE blown film can be characterized as tough and flexible. The toughness is derived from a good combination of strength and elongation, particularly when processed with high machine and transverse direction orientation. Flexibility results from low crystal content. LDPE bags provide a soft feel compared to the crinkly feel of HDPE bags. However, LDPE is not as stiff or strong as HDPE.

1.1.1.2 High Density Polyethylene (HDPE)

High density polyethylene (HDPE) is synthesized by a method very different from that used for LDPE. As a result, very linear chains are produced. In fact, HDPE is generally polymerized with a small amount of comonomer that leads to a few short chain branches placed intentionally along the main chain to make the polymer easier to process (Figure 1.4). A high degree of linearity results in a high percentage of crystallinity (i.e., high density). HDPE is generally in the density range of 0.941 to 0.965 g/cm^3.

Processing HDPE is somewhat different than processing LDPE. Because of its higher degree of crystallinity and more consistent molecular structure, HDPE melts at a higher temperature (265 to 275 °F, 130 to 135 °C) and has a narrower processing window. It also requires higher screw torque, hence more motor power. To promote good solids feeding via high barrel/pellet friction, grooved feed throats are often used.

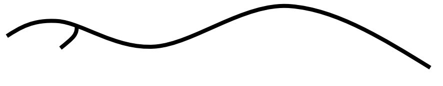

Figure 1.4 Schematic representation of an HDPE molecule showing high linearity with a small amount of short chain branching

One of the most obvious differences between processing HDPE and LDPE is that HDPE is usually run with a high frost line height (long stalk or wine glass shape, see Figure 1.3). The frost line height is generally on the order of eight to ten times the die diameter. HDPE tends to have lower melt strength than LDPE because of a