Polyethylene Film Processing Guide

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POLYETHYLENE FILM PROCESSING GUIDE

Polyethylene is a semi-crystalline polymer that is used extensively due to its unique combination of properties, cost and ease of fabrication. All grades of Formosa Plastics' *Formolene®* polyethylene resin consist of both polymer resin and antioxidants. Other additives, like anti-stats, slip agents and anti-blocks, are added to impact specific functionality. The polymer may be either a pure homopolymer, made by polymerizing ethylene, or a copolymer made from ethylene and another monomer, such as butene-1 or hexene-1.

Polyethylene can be processed by a variety of fabrication techniques such as film/sheet extrusion, injection molding, blow molding, rotational molding, pipe extrusion and profile extrusion. This guide refers specifically to film extrusion. There are three main ways to extrude film: blown, cast or extrusion coating.

There are many different machinery manufacturers for each of these categories, with each machine operating slightly differently. Formosa's *Formolene®* polyethylene resin product can be used successfully on all of these machines to produce various types of film – from trash can liners to barrier films.

More information on Formosa Plastics and our *Formolene®* polyethylene resin products is available at www.fpcusa.com.

INTRODUCTION

This processing guide focuses on how to produce films made from either high density polyethylene (HDPE) or linear low density polyethylene (LLDPE) resins.

The HDPE FILM Resins section covers key terms and experience specific to polyethylene resins in general, and HDPE resins specifically. It is organized into five subsections:

A. Blown Film Extrusion
B. Blow-Up Ratio
C. Extrusion Conditions
D. Processing Conditions
E. Extruder And Die Temperature Settings

The LLDPE Film Resins section covers key terms and experience specific to LLDPE resins. It is organized into two subsections:

A. Blown Film Extrusion
B. Extruder And Die Temperature Settings

Table 1 presents a very useful polyethylene film processing troubleshooting guide.

The information, terminology and experience provided in this guide compile many years of technical and operational knowledge into one handy resource, useful in most situations most of the time. For more in-depth processing and troubleshooting assistance, it is recommended that the processor work closely with the equipment manufacturer and Formosa Plastics' Technical Service Department.

I. HDPE FILM RESINS

Formosa Plastics produces a family of *Formolene®* branded high density polyethylene (HDPE) film resins for mainly blown film applications. The workhorse of Formosa Plastic's HDPE film resins is the *Formolene®* High Molecular Weight High Density Polyethylene (HMW-HDPE) resin product line, which is produced using a unique Nippon Petrochemical bimodal process. These HMW-HDPE film products are designed to have a broad, bimodal Molecular Weight Distribution (MWD) that provides both excellent extrusion processing and physical film properties.

Formosa Plastics also produces a family of conventional HDPE film resins from our Phillips Loop Slurry process. These HDPE film resins from this process are categorized into two types of resins: Medium Molecular Weight High Density Polyethylene (MMW-HDPE) film resins and MMW-HDPE Moisture Vapor Transmission Rate (MVTR) barrier film resins.

The family of *Formolene*® brand HMW HDPE film resins range in density from 0.949 to 0.953 with a melt index ranging from 0.040 to 0.15. These resins are designed with different melt index, density and/or additive packages for a variety of applications. Technical Data Sheets for these products are available at www.fpcusa.com/pe/index.html.

Films produced with HMW and MMW HDPE resins exhibit high impact and film stiffness, as well as good tear strength and excellent tensile strength. The combination of a broad, bimodal MWD, low melt index and high density of the *Formolene*® brand HDPE film resins provide an excellent balance of film performance properties for a variety of film applications.

Formolene® brand HDPE film resins are easily processed into very thin gauge films as low as 6 microns (0.25 mils), as well as into heavy gauge films on the order of 96 microns (4.0 mils) or greater. The broad MWD of *Formolene*® brand HDPE film resins enables them to be processed at lower melt temperatures than competitive HMW HDPE blown film resins. This provides for better bubble stability and gauge control, as well as improved energy savings.

Formolene® brand HDPE film resins are designed with excellent stabilization packages to protect the integrity of the polymer from degradation, especially for applications requiring a high level of trim recycle such as grocery bags commonly referred to as “T-Shirt” bags due to their resemblance to the undergarment.

A. BLOWN FILM EXTRUSION

Two basic methods are used to convert resin into an extruded film: blown film extrusion or cast film extrusion. In both methods, the polymer is melted by subjecting it to heat inside the barrel of an extruder and then forcing the molten polymer through a narrow slit in a die. The slit may be either a straight line (cast extrusion process) or in a circle (blown film extrusion process). The resulting thin film has either the form of a sheet or a tube, the later often referred to as a bubble. In either configuration, as the film comes out of the die, it is cooled and then rolled up on a core.

Extruders come in two forms: conventional smooth bore or grooved feed extruders. In North America, the dominant extruder type in use is a smooth barrel extruder, which is primarily used to process various types of resins. Grooved feed extruders optimize the production process by increasing rates, while reducing melt temperatures and increasing the process stability. The grooved feed sections were created to increase the friction between the polymer and the barrel surface. This is needed to process resins with high viscosity, such as HMW-HDPE resins.

Formolene® branded HDPE film resins can be processed on conventional smooth bore extruders or grooved feed extruders. The HMW-HDPE film resins are processed on grooved feed extruders and MMW-HDPE and HDPE MVTR barrier resins are processed primarily on smooth bore extruders. While MMW-HDPE resins can be processed on both types of extruders, HMW-HDPE cannot be effectively processed on a smooth bore extruder.

Grooved feed extruders generally have a relatively shorter length than smooth barrel extruders. The “Length/Diameter” (L/D) ratio is used to determine the screw length and size. Grooved feed extruders have an L/D of 21:1 to 28:1. Smooth bore extruders have a longer L/D, in the range of 24:1 to 30:1.

B. BLOW-UP-RATIO (BUR) AND POLYMER ORIENTATION

To produce the best physical properties in an extruded film, the proper balance of film orientation in the machine and transverse direction of a film must be achieved. This relationship is achieved by adjusting the blow up ratio of the film. The blow up ratio (BUR) is the ratio of bubble diameter to the die diameter; it indicates the amount of stretching the polymer is undergoing during the shaping of the film.

$$\text{Blow Up Ratio (BUR)} = (0.637 \times \text{Lay-Flat Width}) / \text{Die Diameter}$$

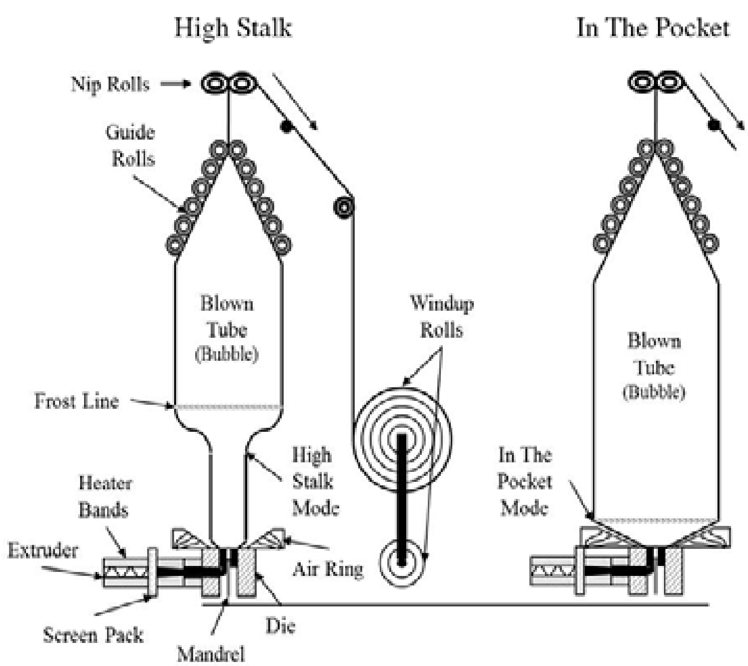
Where:

- *Lay-Flat* is the width of the collapsed film
- *Die Diameter* is the fixed diameter of a given die

The HMW-HDPE blown film lines typically have small diameter dies to achieve the relatively high BUR ratios required to obtain optimum film properties. Other polyethylene resins, such as low density polyethylene (LDPE) and linear low density (LLDPE) resins, normally operate at much lower BURs of 2 to 3. The typical die gaps for HDPE blown film lines are 1.0 to 1.5 mm (40 to 60 mils), which are narrower than die gaps used for conventional LDPE and LLDPE blown film lines.

Figure 1

HMW HDPE AND LLDPE BLOWN FILM



As Figure 1 shows, HDPE blown films lines have a very unique “High Stalk” bubble shape. The stalk height recommended for HMW HDPE blown film lines is 7 times to 9 times the die diameter. The characteristic high stalk bubble shape used for HMW-HDPE Blown film production results in a very high frost line, which is the transitional phase from molten polymer to solid film. A high frost line enables the polymer to achieve a balance of film properties by imparting more bi-axial molecular orientation in the film in the transverse direction (TD) to match the machine direction (MD) orientation.

Bi-axial orientation of the polymer molecules in a blown film is important to achieve a balance of the film’s physical properties. Bi-axial orientation of HDPE blown film is much more difficult than with either LDPE or LLDPE blown film due to the inherent differences of the polymer structures. Long side chain molecular branching is prevalent in LDPE and to a lesser degree in LLDPE, but HDPE has very few side chain branches and they are “short”, not long. It is very easy to orient HDPE blown film in the machine direction; achieving accurate transverse or cross direction orientation is much more difficult.

The “High Stalk” bubble shape for HDPE blown film allows more time for the HDPE film to cool before it reaches the region where the bubble is blown out to its maximum bubble diameter. This region where the bubble is enlarged is where the film is being stretched primarily in the TD direction and the TD orientation is being generated. The cooler the film is when it reaches the top of the stalk where the TD orientation begins to be generated greatly increases the amount of the TD orientation achieved in the finished film.

“Cool” film also enhances the amount of the TD orientation retained in the final film. It also retards the relaxation of the polymer molecules that were orientated in the TD direction. After the film passes through this TD orientation region, it enters the final stage of the process where the film is traveling from the frost line up to the nip rolls at the top of the film line tower. At this time, the film is being stretched primarily in the MD direction. The relaxation of the polymer molecules that were oriented in the TD direction is more difficult in “cold” film, so the TD orientation is retained better. Conversely, if the film is “hot”, the polymer molecules can relax easily and the amount of TD orientation in the final film is significantly reduced.

C. EXTRUSION CONDITIONS

Formolene® brand HDPE film resins are normally processed at melt temperatures of 380°F to 430°F. (195°C to 220°C). The melt temperature should be maintained at the lowest temperature possible to optimize easy processing and to maximize balanced film physical properties. Lower melt temperatures will enhance bubble stability, gauge control and minimize die lip build-up. *Formolene*® brand HDPE film resins have a broad MWD that enables processing at lower melt temperatures than most competitive resins and still minimize the possibility of melt fracture.

Formolene® brand HDPE film resins can be processed using 100% virgin resins on HDPE blown film lines. HDPE film resins are designed with excellent process stabilizers that protect the resins from degradation and enable high levels of reprocessed ("repro") film. In addition to various colors and as high as 30 to 50% "repro" resin, most film producers may also blend in small amounts (< 10%) of LLDPE, LDPE or calcium carbonate master batches to enhance extrusion and heat sealing performance. The HMW and MMW HDPE resins are compatible with most color and calcium carbonate master batches commonly used in the film industry.

Blending HDPE film resins with MMW MDPE resins is also common for some applications.

Formosa Plastics' Technical Services Representatives work with customers to discuss any specific blends or formulations needed to achieve the desired film properties.

D. EXTRUDER AND DIE TEMPERATURE SETTINGS

Correct extruder and die temperature settings are essential for producing the most optimal film in terms of both physical properties and extrusion efficiency. Typical settings for an HDPE film extruder are shown below.

Recommended HDPE Film Resin Temperature Settings

	Zone #1	Zone #2	Zone #3	Zone #4	Adapter	Die #1 (Lower Die)	Die #2 (Upper Die)
Degrees F	370	380	390	390	420	430	435
Degrees C	190	195	200	200	215	220	225

Note: For HDPE resins with melt temperatures from 380°F to 430°F (195°C to 220°C)
Adjust the extruder settings up or down 10°F to achieve the lowest melt temperature possible on each film extrusion line. This will achieve the best film properties and the best balance in MD and TD orientation for any given BUR. Adjust the die temperature settings to match the melt temperature based on the actual melt temperature to enhance the film appearance and help prevent melt fracture.

II. LLDPE FILM RESINS

Formosa Plastics provides narrow molecular weight distribution *Formolene*® brand butene copolymer LLDPE resins for film applications. Formosa supplies LLDPE grades with a variety of additive packages. Grades are formulated with different levels of slip, anti-block and processing aids. Grades without any slip, anti-block or processing aid are also available. Formosa's *Formolene*® brand LLDPE resins can be used as 100% of the film construction, or can be blended with other resins such as LDPE, HDPE, EVA, etc. *Formolene*® brand LLDPE resins can also be successfully used in coextruded film structures.

A. BLOWN FILM EXTRUSION

Formolene® brand LLDPE blown film resins are typically processed on smooth barrel extruders. Standard extruder barrel lengths can range from 24:1 to 30:1.

As noted, the film blow-up-ratio (BUR) will be determined from the blown film die diameter and the desired film lay-flat. Since it is not easy to measure the bubble diameter directly, the bubble diameter is calculated from the lay-flat width -- the bubble diameter is 0.63 times the film lay-flat width. For LLDPE, standard BURs are between 2:1 and 3.5:1. Bubble stability problems are typically observed if the BUR is too high; excessively high MD/TD oriented film is produced when the BUR is too low.

Due to the relatively high shear viscosity of narrow molecular weight distribution resins, LLDPE resins tend to be extruded through a wide die gap, on the order of 90 mils (2.3 mm) to 110 mils (2.8 mm). If the film formulation includes a processing aid, a narrower die gap can be used. It is unusual, however, to extrude 100% LLDPE through a blown film die gap narrower than 65 mils (1.6 mm), even with a processing aid. If the die gap is too narrow for the resin being extruded, the film could be subject to melt fracture, high head pressures, etc. Conversely, if the die gap is too wide for the resin being extruded, bubble stability problems and highly oriented film can result.

The LLDPE frost line height (FLH) is approximately the height above the blown film die where the molten polymer solidifies. The FLH is typically controlled by the adjusting the volume of cooling air from the air ring. In practice, generally, the cooling air is adjusted to maximize output rate and bubble stability. However these adjustments will also have some impact on film properties. At a lower FLH, LLDPE film optical properties will be improved, but the film mechanical properties will exhibit more MD/TD orientation. Conversely, LLDPE film mechanical properties will be more balanced, but film clarity will suffer at higher FLHs.

B. EXTRUDER AND DIE TEMPERATURE SETTINGS

Appropriate temperature profiles result when resin melt temperatures are between 390ºF (200ºC) and 450ºF (230ºC). Although each extrusion line will be different, a good starting temperature profile would be 380ºF (195ºC) across the extruder and 420ºF (215ºC) for the adapter and die temperature zones.

Recommended LLDPE Film Resin Temperature Settings

	Zone #1	Zone #2	Zone #3	Zone #4	Adapter	Die #1 (Lower Die)	Die #2 (Upper Die)
Degrees F	380	380	380	380	420	420	420
Degrees C	195	195	195	195	215	215	215

Note: For LLDPE resins with melt temperatures from 390°F to 450°F (200°C to 230°C)

Due to the rheological behavior of LLDPE in extension, proper cooling of the molten bubble is essential to achieve good bubble stability and, therefore, acceptable production rates. At a minimum, 100% LLDPE film lines should be equipped with a dual lip air ring. More sophisticated cooling equipment, such as internal bubble cooling (IBC), can further increase production rates.

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Table 1
Polyethylene Film Processing Troubleshooting Guide

Common film processing problems and possible corrective actions

1. Low Dart Impact
2. Low MD Tear; Split Film
3. Melt Fracture
4. Poor Bubble Stability
5. Gels, Holes, Bubble Breaks
6. High Gauge Variation
7. Die Line
8. Port Line
9. Low Extruder Output
10. High Extruder Pressure
11. Poor Roll Geometry

Abbreviations: *BUR = Blow-Up Ratio* *MD = Machine Direction* *MI = Melt Index*

Problem Observed	Possible Causes	Possible Corrective Actions
1. Low Dart Impact	1. High melt temperature 2. Inadequate cooling	1. Reduce melt temperature 2. Increase cooling, neck height, BUR
2. Low MD Tear / Split Film	1. Too much film orientation 2. Resin density too high 3. Thermal degradation of the polymer during extrusion	1a. Increase BUR 1b. Decrease die gap 1c. Increase frost line height 2. Use a lower density resin 3a. Decrease melt temperature 3b. Add an antioxidant masterbatch
3. Melt Fracture	1. Low extrusion temperature 2. Inadequate die gap 3. Excessive friction at die lip 4. Resin MI too low for extrusion conditions or equipment	1. Increase melt temperature 2. Increase die gap 3a. Lower processing rate 3b. Add processing aid to reduce COF 4. Use a higher melt flow resin
4. Poor Bubble Stability	1. Melt temperature to high 2. Too much or too little cooling air 3. MI too high for process 4. Output rate too high 5. Misalignment of nip rolls	1. Reduce melt temperature 2. Adjust cooling air 3. Lower processing rate 4. Reduce output rate 5. Realign nip rolls
5. Gels, Holes, Bubble Breaks	1. Contamination 2. Excessive regrind or reprocessed material 3. Dirty screw, die or screen pack 4. Poor mixing	1. Check for contamination in silos, transfer systems, colors and other masterbatches 2. Stop or reduce the ratio of regrind and reprocessed material until problem improves 3. Clean screw and die plus change screen pack 4a. Check screw 4b. Check heater bands and thermocouples
6. High Gauge Variation	1. Dirty screw, die or screen pack 2. Uneven cooling	1a. Clean screw and die plus change screen pack 1b. Clean die 2. Check temperature settings & recalibrate
7. Die LIne	1. Dirty or damaged die lip 2. Insufficient purging	1. Clean or repair die 2. Increase purge time between transitions
8. Port lines	1. Resin viscosity too high for die design 2. Die and melt temperature off 3. Melt temperature too low	1a. Use a resin with a higher MI 1b. Consider using a processing aid 2. Narrow the temperature differences between the die and polymer melt temperature 3. Increase the melt temperature
9. Low Extruder Output	1. Melt temperature too high	1a. Reduce melt temperature. 1b. Check external cooling. 1c. Check extruder screw wear.
10. High Extruder Pressure	1. Contamination	1a. Check extruder heaters, screen pack. 1b. Check for contamination.
11. Poor Roll Geometry	1. Poor bubble stability	1a. Reduce melt temperature. 1b. Increase cooling, die temperature. 1c. Clean die.

Our Vision

Each individual in our company takes personal pride in achieving performance excellence. Through our common goal we aspire to explore, challenge, and strive to exceed the best industry practice in every task performed.

This enables us to maintain global competitiveness, achieve healthy, continual growth that will benefit society, and fulfill our commitment to our customers and responsibility to our colleagues.

Our Guiding Principles

Everything we do at Formosa is measured against the following Guiding Principles:

- **Integrity –** Because no successful bond can be formed without trust, we are fair and honest in all our relationships and transactions, whether they be with customers, suppliers, employees or the communities in which we operate.

- **Customer Service** – For our businesses to grow and succeed, we must provide our customers with service that satisfies their current requirements and anticipates their future needs.

- **Environmental Responsibility –** We cannot measure success solely in terms of profits. We must also be mindful of our environmental performance and responsibilities. This responsibility is not a burden, but rather, an opportunity that will enable us to continue to operate and improve our standing in the community.

- **Workplace Health and Safety** – We are committed to the health and safety of our employees and the communities in which we operate. Through the joint efforts of every employee, we shall keep our environment clean and our workplace free of health and safety hazards, for ourselves, for our communities and for our future generations.

Please visit www.fpcusa.com for more information on Formosa Plastics and our people, products, safety & environmental protection efforts and production facilities.

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