

Applied Engineering Tools for Recycling

*Using Recycled HDPE Resins
in Blown Film Applications*



Using Recycled HDPE Resins in Blown Film Applications

Prepared for

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1.0 INTRODUCTION

This tool provides a guideline for designing and conducting trials to incorporate post-consumer or post-industrial high-density polyethylene (HDPE) resins into monolayer blown film products. Recovered HDPE, most commonly originating from products like plastic, non-transparent, milk and juice jugs, is the most widely used post-consumer resin (PCR) in blown film operations (3).

Common products formed by the blown film process include garbage bags, can liners, agricultural films, grocery bags, multi-layer films, and thin films for paper and tissue products. Grocery bags and trash bags are two end-products available today that often contain PCR.

The development of this tool is based on a case study conducted in Washington state with a grocery bag manufacturer. The case study tested various levels of PCR HDPE content and resulted in incorporation of 50% post-consumer HDPE (natural HDPE from milk jugs), into grocery (carry-out) bag production. The methodology presented describes how to conduct test trials to determine the optimum blend and processing parameters that may be applicable to other recycled resins in blown film products.

It is difficult to predict how different material blends will interact with changes in materials and changes in process variables. The new blends may enhance or reduce certain end-product properties. The goal of the process trials is to produce a product that meets or exceeds customer requirements. Understanding the end-product requirements and the effects of different blends of materials on film properties will help determine blend formulas, processing parameters, and whether the final recycled content product will meet customer requirements.

The following topics and guidelines are presented in the following sections:

- Section 2.0 - Benefits of using PCR in blown film applications;
- Section 3.0 - Blown film process;
- Section 4.0 - Using recycled HDPE resin in blown film applications;
- Section 5.0 - Trial design considerations;
- Section 6.0 - Trial planning and set-up;
- Section 7.0 - Trial run and evaluation; and
- Section 8.0 - References.

2.0 BENEFITS OF USING PCR IN BLOWN FILM APPLICATIONS

There are many beneficial uses of the different grades of recycled HDPE. Some potential end-product that utilize recycled HDPE include the following:

Recycled HDPE Resin	Typical Applications for Recycled Resin
Bottle-Grade HDPE - Natural (e.g., milk jugs)	<ul style="list-style-type: none"> • Bottles (e.g., laundry detergent, motor oil) • Semi-rigid containers for some food products (e.g., margarine) • Base cups for pet bottles • Residential and commercial drainage pipe • Toys • Pails and drums • Traffic barrier cones • Milk bottle crates, trash cans and curbside collection bins • Grocery bags • Strapping
Bottle-Grade HDPE - Pigmented (e.g., detergent bottles)	<ul style="list-style-type: none"> • Interior layers of bottles • Flower pots • Plastic lumber
Film-Grade HDPE (e.g., grocery bags)	<ul style="list-style-type: none"> • Bags (e.g., grocery and trash bags) • Agricultural film

Incorporating recycled HDPE into new products can achieve cost savings, and provide a marketing tool for manufacturers serving environmentally responsive retail customers. The impetus for large corporate-end users and governmental operations to incorporate and purchase recycled-content products is rising for these same reasons and due to government mandates to buy recycled-content products. Technically, process modifications to incorporate recycled HDPE are minimal with up-do-date equipment. Finally, there is potential for enhancement of end-product properties with incorporation of PCR in certain applications. The case study supporting this document resulted in increase tensile strength of the grocery bag product.

Although applications for use of the different grades of recycled HDPE are varied, as shown in the above list, this document focuses on incorporation of recycled, bottle-grade HDPE into blown film products.

3.0 BLOWN FILM PROCESS

In the blown film production process, plastic pellets or flakes (and any additives) are premixed, melted in an extruder, propelled into a die which causes the material to flow around a mandrel and emerge through a ring-shaped opening in the form of a tube. Air is introduced into the tube causing it to expand and form a bubble. The air is contained in the bubble by the die at one end and by the nip rolls at the other end. Even air pressure is maintained to ensure uniform thickness of the film bubble. Air flow around the outside of the bubble cools and solidifies the melt.

Radial stretching and axial stretching of the formed bubble (away from the die), orient the plastic, improving strength and properties. After solidification, the film bubble moves into a set of pinch rolls to flatten and roll the material onto a winder.

Extrusion equipment and accessories vary. Proper blending of materials prior to introduction into the extruder is enhanced by continuous flow blending equipment. The less complex premix for batch manufacturing premixing may suffice but requires closer attention during mixing.

For the extrusion process, barrier screws are recommended by many suppliers for mixing virgin/recycled blends to achieve requisite mixing (3). Because recycled resins may have higher contamination levels compared to virgin materials, continuous screen changers may be cost effective and will prevent downtime. Recommendations on other equipment specifications and accessories vary from different suppliers and with different virgin/recycled blends. Some of these issues are discussed further in Section 4.0 and 5.0.

Some film extrusion lines utilize in-line printing equipment and forming machines (e.g., bag-manufacturing), while less sophisticated extrusion lines form the film or sheet first, then print or form the final product (e.g., bags) off-line.

Coextrusion is a variation of the blown film process, using a die designed with multiple flow channels so that multiple layers may be formed. Multiple layers are typically used to protect the product from moisture, air, etc. The number of layers can range from two to as many as ten layers in complex systems. This tool may be modified to and applied to coextrusion.

4.0 USING RECYCLED HDPE IN BLOWN FILM APPLICATIONS

Common virgin resins used in blown films include polyethylenes (high density, low density and linear low density), polypropylenes, ethylvinyl acetate (EVA), and flexible polyvinyl chloride (PVC). The typical thickness of blown films range from 0.00254 mm to 1.27 mm (0.0001 inch to 0.050 inch).

HDPE has a high recyclability potential because nearly all HDPE containers are made from same-grade resins, a fractional melt index homopolymer. This results in a homogeneous feedstream with consistent material characteristics evident in predictable performance properties and flow (processing) characteristics.

Recycled HDPE is suitable in many blown film applications where product clarity is not important. Although some deficiencies may occur with the use of PCR, such as film imperfections from gel content, the recycled HDPE has been shown to produce equal or superior performance properties compared to some traditional virgin resin grades of film HDPE. Also, in appropriate concentrations, and slight equipment changes to compensate for any PCR deficiencies, the resin may not substantially affect processing (3, 4).

Bottle-grade, natural HDPE is the unpigmented material in plastic milk jugs and similar containers. Bottle-grade, pigmented HDPE is the resin typically used in colored, opaque plastic detergent bottles and similar products. In most blown film applications, it is necessary or preferable to have color-segregated HDPE, sorted into natural (which could be used in white or light colored films), and pigmented (which could be used in darker colored films). Additionally, different HDPE grades, e.g., bottle-grade versus injection-grade, should be segregated prior to further processing for use in blown film applications.

End-products regulated by the Food and Drug Administration (FDA) may restrict or prohibit the use of post-consumer plastics in that product if the recycled material will have direct contact with foods or beverages. However, this may not apply to the use of recycled HDPE in the inner layer(s) of a multi-layer film product.

4.1 **Specifications for Recycled HDPE Used in Blown Film Applications**

Depending on the application, the recycled HDPE specifications, definitions, and discussions presented in Table 1 may be important when sourcing the PCR.

Material performance may depend on the addition of pigments for color, fillers for opacity, antioxidants for short term processing stability, UV stabilizers for weather resistance. They are added in the form of concentrates or liquids at the point of extruding the flake material during pelletizing or forming into a final product. Additives are varied and process or product-specific, and therefore are left to the product manufacturer and recycled HDPE processor to specify.

4.2 *Equipment Maintenance and Wear*

Normal wear and tear on blown film equipment may increase with recycled resin blends when compared to virgin blends, especially in older extrusion equipment. This results from ineffective mixing as the gap between screw flights and barrel diameter grows larger. A tight tolerance for this dimensional gap increases the effectiveness of mixing (3).

Table 1: Discussion of Specifications for the Recycled Feedstream

Property	Definition	Discussion	Suggestion
Form	Recycled resin is most commonly converted to regrind or pellets for reuse.	Due to surface finish requirements, pelletized HDPE is recommended to ensure contaminant removal and decrease lot-to-lot variation. Clean, post-industrial HDPE regrind may also be acceptable, however, flake is more prone to retaining moisture, which can affect processing.	Post-consumer: Pellet Post-industrial: Regrind or pellet
Color	Natural HDPE is a semi-white, semi-transparent material. Pigmented HDPE is usually opaque and of various colors.	Natural HDPE is acceptable for light colored products. Pigmented HDPE may be used in dark colored products. If color of the end-product is important, incoming pellet should be checked for discoloration and measurable color values for L*, a*, b*, and Δ E.	Depends on application. Agreement from supplier and buyer for L*, a*, etc.)
Grade	The grade of the resin, e.g., blow mold grade, injection mold grade, or film grade.	Generally, it is best to use the same grade of a recycled resin into a product made from the same grade in the same process (e.g., use recycled blow mold grade into a new blow-molded product). However, recycled bottle-grade (blow molded) HDPE has been used successfully in blown film products.	Depends on processing capability.
Feedstock origin	Certification of the resin source (previous use), including post-consumer or post-industrial content.	Supplier should certify the post-consumer and post-industrial content. The certificate should state that the material is 100% recycled content.	Depends on processing and product goals or specifications for recycled content.
Polymer density	Mass in air per unit volume of material at 23 degrees Centigrade. Typical units: grams per cubic centimeter (g/cc).	Lower density blends often have better mechanical properties in film applications. Density is determined by ASTM specification D792 - <i>Density And Specific Gravity (Relative Density) of Plastics By Displacement</i> or D1505 - <i>Density of Plastics By The Density-Gradient Technique</i> .	0.960 ± 0.010 grams per cubic centimeter (5)

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Table 1: Discussion of Specifications for the Recycled Feedstream

Property	Definition	Discussion	Suggestion
Melt index (MI)	The rate of extrusion of molten resin over time through a die of a specified length and diameter under prescribed conditions of temperature, and loading.	The MI of the recycled-content blend may affect processing and melt/mixing characteristics. Blends with a lower MI may decrease throughput and require increased mixing to obtain consistent mechanical properties. Note: PCR resins usually have little variability in MI, because the make-up of the resin consists of many different materials, which will result in a somewhat universal average for the MI (3).	0.65 ± 0.20 grams/10 min (5)
Contamination	Undesirable contaminants may include) non-polyethylene plastic contamination, labels, dirt, foil, other polymeric contaminants such as PET or PVC (from caps and closures), metal, glass, or other.	Incoming pellet should be checked for visible contamination including black specifications in the pellets. Incoming regrind or reclaim should be inspected for undesirable contaminants.	Not Available.
Gel count	Gel contaminants found in recycled HDPE are materials composed of oxidized or high molecular weight materials.	The presence of gels in plastic films is objectionable due to appearance defects in the film, and to problems associated with printing on the film. Gel count is determined by ASTM D3351-93 - <i>Gel Count of Plastic Film.</i>	Not Available.
Volatiles	Volatiles are a type of chemical contaminant that may flash off during processing depending on the flash point of the chemical(s).	Certain volatiles may contribute to gassing and bubble formation during processing and cause voids in the film product.	0.10% maximum (5)
Pellet count	Number of pellets in a one gram sample.	Pellet count is related to bulk density (see discussion below).	50-80 pellets/gram (5)

Table 1: Discussion of Specifications for the Recycled Feedstream

Property	Definition	Discussion	Suggestion
Bulk density	The mass per unit volume of material. Reported as g/cc, kilograms per cubic meter (kg/m^3), or pounds per cubic foot (lb/ft^3).	Bulk density indicates the porous nature of the material, as well as voids in the material. Flake has a lower bulk density than pellets (7). A bulk density for recycled HPDE in the low range of 10-20 pounds per cubic foot, requires deeper flight depth to process the melt properly and maintain equal throughput compared to pellets.	Not Available.

5.0 TRIAL DESIGN CONSIDERATIONS

Because each film production operation is different, processing variables and testing procedures should utilize current company protocols and practices when possible. Baseline information on film processing parameters and product properties for standard products are documented before starting the trials. Samples of the original, standard product are retained to compare with trial products. This important baseline information is needed to analyze and compare to data collected during the recycled material trials. The processability, as well as performance and appearance of trial products are compared to the original, standard products in the analysis of the trial results.

Three key processing factors are important: selection of compatible virgin blend materials, effective mixing, and strict process controls (3). Each of these issues is described below.

5.1 Selection of Virgin Blend Materials

The formulation of virgin resins with recycled HDPE is significant because the recycled, bottle-grade HDPE content has the potential to affect various properties of the film product. Table 2 shows the effects of incorporating recycled HDPE with virgin blown film resins.

Recycled, bottle-grade HDPE generally has a higher polymer density than standard blown film resins. Consequently, the density of recycled blends is higher than those of virgin blown film resins. This has the potential to affect impact strength and tear strength properties of the film product.

Using a lower density virgin resin to bring down the overall blend density may be necessary. Dow, Inc. recommends the use of ultra-low density polyethylenes (ULDPE) to lower the overall density of recycled-content blends. OxyChem Inc. recommends the use of higher-molecular weight HDPE for applications with PCR levels above 25% because it improves tear strength properties. Mobil Polymers advocates its hexene-linear low density polyethylene (LLDPE) for accommodating PCR without loss of film strength (3).

It is also important to choose the optimum level of recycled resin. At certain ratios, the recycled HDPE content can actually improve end-use properties of the film. Processors should experiment with a range of recycled HDPE content levels to obtain the optimum end-use properties.

Table 2: Blown Film Product Properties with Recycled HDPE and Virgin Resin Blends (3)

Property	Recycled HDPE Blended With:		
	LDPE	LLDPE	High Molecular Weight HDPE
Polymer Density	increases	increases	no change
Melt Index	decreases	decreases	increases
Ultimate Tensile Strength			
Machine direction	increases	no change	decreases
Transverse direction	increases	no change	decreases
Ultimate Elongation (%)	decreases	decreases	decreases
Dart Drop Impact Strength	decreases	decreases	decreases
Tear Strength			
Machine direction	decreases	decreases	decreases
Transverse direction	increases	increases	no change
Haze	increases	increases	N/A
Gloss	decreases	decreases	N/A

Source: Quantum Chemical.

5.2 Effective Mixing

A homogeneous material blend is important when mixing recycled resin(s) with virgin resin(s) (and other additives or colorants), both prior to introduction into the extruder, as well as during melt mixing within the extruder. Resin from recycled HDPE milk bottles have a higher melting point and viscosity when compared to other polyethylenes. Because milk bottle resins were not designed for blown films, their melt characteristics are much different than standard blown film resins, such as low density polyethylene (LDPE) or linear low density polyethylene (LLDPE) (3).

Proper blending of materials prior to introduction into the extruder is important in any blended plastic extrusion process, but even more so for PCR/virgin blends. Therefore, low tech pre-mixing equipment may require closer attention during mixing to ensure a homogeneous feedstream into the extruder.

The primary function of the extruder is to provide a continuous stream of uniformly molten polymer to the mold or die for configuring into a final shape. Melt mixing within the extruder is very important because of the different properties of the blended resins. For virgin/PCR blends, a barrier screw, designed to accommodate blends of multiple materials, is recommended to achieve the requisite mixing (3).

To achieve proper melt mix in the extruder, low-shear mixing and controlled melt temperatures are very important (3). Low shear mixing avoids degradation of the recycled resin. Since the recycled resin has already undergone at least one heat history, controlling melt temperature to prevent excessive heating is also important.

The best way(s) to achieve low-temperature, low-shear mixing for recycled HDPE and virgin blends is debatable. Some processors recommend using long extruders in the 30:1 length to diameter (L/D) range to impart less high-intensity shear. The longer extruders mix blends of materials better and have the flexibility to process any material. However, cavity-transfer mixers are not recommended for low-shear mixing needs in a longer extruder such as this (3).

An alternative recommendation from another supplier advocates the shorter screw extruder, in the 20:1 L/D range, to decrease the residence time of the material (3). In a blend of recycled HDPE with high molecular weight HDPE, one supplier has a 20:1 extruder running up to 33% PCR. For mixing of recycled HDPE with virgin LDPE or LLDPE, most suppliers agree that a longer extruder works best.

5.3 Strict Process Controls

Strict process and quality controls are critical in recycled/virgin blends, mostly to compensate for inconsistencies inherent with recycled resins. The most important controls are on feedstream consistency and contaminant levels, mixing, filtration, and melt temperature.,

Work with recycled resin supplier(s) to ensure a consistent supply from shipment to shipment, and to ensure contaminant removal to a satisfactory level for the specific application. Controlling loose contamination, gel count, and volatiles content is important, although loose contamination is usually less of an issue in pelletized material than in flake.

Recycled resin inconsistencies such as contamination and melt flow variation can be addressed by the use of specialized blending equipment, such as gravimetric yield controls and gear pumps which can accommodate the inconsistencies of PCR materials.

Continuous screen changers may be useful minimize potential downtime caused by contaminants. Otherwise, screen change intervals based on pressure build-up at a specific set point may be more efficient than screen changes on a fixed time interval.

5.4 Troubleshooting

As the trials are conducted, a variety of results may occur. Table 3 discusses potential troubleshooting tips for specific problems or inconsistencies in the trial outcomes.

5.5 *Property Testing*

Property testing is important to meet customer standards, to provide quality control; to verify the manufacturing process, and to establish a history for new formulations and processing. Product testing of bags and films determines variance in film characteristics due to the addition of PCR materials. Use of standardized tests is recommended for achieving results that are familiar and easily communicable.

The specific material and mechanical property tests will vary depending upon performance requirements and customer specifications. Some of the most common tests for blown film properties are dart drop impact strength, tensile strength, tear strength, haze, and gloss. However, additional tests may be required for specific applications. For recycled-content products, these properties are equally or more important than in 100% virgin products.

The methods of testing often vary depending on the capabilities of the manufacturer. For example, testing the tensile properties of bags may entail filling the bag with a weight rather than using the traditional tensile testing machine per American Society for Testing and Materials (ASTM) specifications. Table 4 discusses several of the common tests for evaluating recycled-content plastic films or bags and the applicable :

Table 3: Troubleshooting Ideas for Quality Issues with Recycled Blends

Quality Issue	Troubleshooting Ideas
Low or variable pressure in the melt	Presence of oil in the blend reduces the frictional contact with the screw and barrel during extrusion. Its pressure can also plasticize the HDPE and contaminate the final product.
Moisture in feedstream	<p>Try a vented screw. Vented screw extruders use heat and pressure to convert excess moisture to steam, which is then vented. Recommended minimum pressure build up after the vent is 2000 pounds per square inch (psi) to avoid accumulation of moisture (3).</p> <p>If using flake, note that it is more prone to moisture retention than pelletized material. Evaluate feasibility of switching to pellets or improving drying of the flake.</p>
High overall blend density	<p>Try a blend with a lower density virgin resin. Dow, Inc. recommends the use of ultra-low density polyethylenes (ULDPE) to lower the overall density (3).</p> <p>Try adding a 10% virgin polyethylene (PE) of a lower density to increase tear strength. Incorporating the use of a lower density PE will bring down the overall blend density.</p>
Dull or streaked finish or surface	Try higher melt temperature.
Glossy finish or surface	Try lower melt temperature.
Inadequate tear strength	<p>Frostline height is one of the factors that may have an effect on strength. Compensate for fluctuating frostline heights by adjusting temperatures, throughput, or airflow.</p> <p>Try adding a 10% virgin PE of a lower density to increase tear strength. Incorporating the use of a lower density PE will bring down the overall blend density.</p> <p>OxyChem Inc. recommends the use of higher-molecular weight HDPE for applications with PCR levels above 25% (3).</p>
Bubble defects in product	<p>Try a greater compression ratio for flake. When the flake does not melt enough prior to a vent it will fill the vent area and prevent the air and any moisture to escape prior to molding thus introducing bubble defects in the product being molded.</p> <p>Use pellet instead of flake. The lower melt strength typical of recycled HDPE blends can cause unstable bubbles and fluctuating neck heights. Try chilled air cooling systems or redesigning the air-flow patterns.</p>

5.0 Trial Design Considerations

	Test for high gel count. Require that the resin supplier control volatiles and gel count in the recycled resin supply.
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5.0 Trial Design Considerations

Table 4: Some Important Properties of Blown Film

Property	Discussion
Tensile Strength	A measure of the maximum stress a material will withstand when subjected to a load in tension. The applicable ASTM test method is D882 -95a - <i>Tensile Properties of Thin Plastic Sheeting</i> . Note: A simpler method is to load an suspended bag or film with weights.
Tear/Shear Strength	A measure of the maximum stress a material will withstand when subjected to a load in shear. The applicable ASTM test method is D 1004-94a - <i>Initial Tear Resistance of Plastic Film and Sheeting</i> .
Dart Drop Impact Strength	A measure of the toughness of the material by introducing a polyaxial load. The applicable ASTM test method for plastic films is D 1709-91 - <i>Impact Resistance of Plastic Film by the Free-Falling Dart Method</i> .
Haze	An optical characteristic which measures clarity or transparency of a material. The applicable ASTM test methods for plastic films are D 1746-92 - <i>Transparency of Plastic Sheeting</i> , and ASTM D 1003 - <i>Haze and Luminous Transmittance of Transparent Plastics</i> .
Gloss	An optical characteristic which measures the reflectance of a material. The applicable ASTM test method is D 2457-90 - <i>Specular Gloss of Plastic Films and Solid Plastics</i> .

6.0 TRIAL PLANNING AND SET-UP

The goals of these trials are to use different blends of materials and to vary machine conditions to optimize the desired end product characteristics. When introducing any new process, piece of equipment, or raw material, allow time for system adjustments and diligent communication with operators, suppliers, and customers. Careful planning is very important, especially during introduction of the process and product, to result in meaningful information to identify the best combination of materials and processing conditions to achieve the desired film properties.

6.1 *Informed Customers*

Keep customers well-informed of transition efforts. In particular, when assessing end-product quality, communicate any pertinent results from the trials and request customer feedback on the final end-product.

6.2 *Benchmarking: Data and Product Specifications*

Retain several samples of the current end-product to test and compare with the final product from trial runs utilizing recycled HDPE.

Review and document the current end-product quality specifications, such as film thickness, tear strength, etc. If these specifications will be different from the recycled content product, document those pertinent end-product quality specifications.

Document the current resin or blend properties, process parameters, and end properties presented in Appendix A, to provide a benchmark to compare current conditions at each step of production. Add additional items to this list as needed. Determine which of the compound and product qualities are critical and denote with a “Y” for “yes.”

6.3 *Planning Trial Conditions and Activities*

Establish and document the initial trial processing conditions based on the benchmark data collected and a conservative estimate on the achievable recycled content level in the blend. Blend formulation and processing parameters will likely be adjusted after the first or second trial based on test results.

The following steps are guidelines to help organize material, processing and test information for trial data comparison, and determine subsequent trial conditions.

1. Record baseline processing conditions and film test characteristics for standard products so this information on the logsheet provided in Appendix A. The information will be used for comparison to the PCR trials.
2. Determine the target goal for recycled content in the film product.

3. Determine a throughput capacity that is expected to yield representative end-products for comparison and testing. Planning the throughput quantity should allow for equipment setting adjustments and line restabilization.
4. Based on the estimated throughput, estimate the time required to run each trial. Equipment operator input is important and useful for this planning step. Include allotted time for cleaning and filling the hopper, equipment warm-up, start-up of the film line, purge time to remove any material in the extruder, and line stabilization. *Note: Estimate conservatively to ensure sufficient time for all of these conditions. This information will determine the practical number of trials given the available time and resources.*
5. Identify supplier(s) for the recycled resins and materials to be used in the trials.
6. Determine the approximate number of trials to conduct based on available time and resources. Assign trial numbers.
7. Design an initial blend formulation scheme for each trial (See Example 1 below). Starting with the minimum targeted recycled content level, increase the percentage of recycled material in the blend by 10% or 20% depending on the number of trials. Document the planned blend formulations in the logsheet in Appendix B.
8. From the plan in step 5, determine the quantity of recycled resin needed. If possible, plan to purchase about 30% more than needed to perform all trials once.
9. Procure the recycled resin. Ensure the lead time meets the trial dates. When received at the processing site, document the material description, vendor, lot number, any material tests supplied by the vendor, results of any receiving inspection and any comments. Some of the material characteristics the vendor may supply are melt index, density, and gel count.
10. Determine and document the planned mixing and extrusion conditions, such as mix time, melt temperature(s), pressure, amperage, air flow, etc. on the logsheet in Appendix C.
11. Determine the set time interval for tracking the process runs. The recommended frequency for checking and recording the film thickness and equipment conditions is between 10 to 15 minutes. Document the time interval in Appendix C.
12. Document the testing requirements for the film end-product. Include all material or mechanical properties required by customer specifications, as well as additional properties considered important in the manufacture and end-use of the product.
13. Educate all operators and test personnel of the trial plan and their responsibilities
14. Collect the necessary supplies: data forms and logsheets, marking pens or flags to identify sections of film to be tested, and a tape measure.

Example 1: If the goal is to achieve at least 50% recycled content and four trials are planned, the following is a potential initial plan for the trials.

Trial Number	Recycled HDPE Content	Virgin Resin Content
1	50 weight percent	50 weight percent
2	60 weight percent	40 weight percent
3	70 weight percent	30 weight percent

4	75 weight percent	25 weight percent
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6.4 Start-Up

The typical start-up operations include the following steps:

- Material preparation
- Line start-up
- Purging of material remaining in the extruder
- Line stabilization

During start-up, allow for warm-up time and stabilization before any test samples are identified. Note and record any differences compared to standard processing. The temperature settings and other machine variables may have to be adjusted several times to obtain acceptable processing conditions. The following is an example of a typical start-up operation:

Material Preparation Steps

1. Based on the percentage of each material in the blend, per the documented plan in Appendix B (Planned), weigh out portions of each ingredient. Record actual weights, and resulting weight percentages of individual ingredients in a second copy of Appendix B (Check the “Actual” box).
2. Purge the hopper and mixing or feeding equipment. During the start-up of each different blend, purge the extruder completely.
3. Prior to placing the mix in the extruder hopper, blend the materials until homogeneous. Record the actual mixing time and process, and any comments in Appendix D.
4. Load the mixed material into the hopper.

Line Start-Up

1. Using the initial equipment conditions determined and recorded in the plan per Appendix C, start up the film line.
2. Start-up the equipment and let temperatures, pressures, amperage, and other machine conditions stabilize so that representative samples for testing comparisons can be obtained.
3. When the line is running and the equipment has stabilized, observe and record all machine measurements and measure the film thickness. Record all information in the first line of the table in Appendix D.

7.0 TRIAL RUN AND EVALUATION

Running the trials involves operation of the equipment for the throughput established in the plan. The equipment will initially run at the stabilized, start-up conditions, however the frostline height, temperature and extruder RPM amperage may need adjustments during each trial to achieve the desired extruder pressure, product quality and throughput.

During the trial runs, equipment settings will be observed and recorded at set time intervals as documented in Appendix C. If or when machine variables are adjusted, the film should be flagged or marked to coincide with changes in process variables. This will help in identifying where process changes were made and their effects on film properties. Note: When using different material blend variations, machine conditions may not have the same effects on film properties. For example, raising the frostline height for Blend A may increase tear strength. For Blend B, lowering the frostline height may increase tear strength.

7.1 Process Run Steps

1. Begin and continue to record process conditions on the set time interval throughout the trial.
2. Note any setting adjustments on the logsheet provided in Appendix D. Flag or mark the film at all adjustments. Measure and record the film thickness at the same time intervals as the process line.
3. If multiple thicknesses are to be run, increase or decrease line speed (or throughput rate) for each new thickness. Record all machine conditions and measured film thickness.
4. Note film smoothness, frostline height and stability, printability, and any other observations or comments from operators on how the recycled processing compares to standard processing.

7.2 Property Testing

The property testing requirements were established and identified in the plan in Appendix B. Property testing should be conducted on multiple samples from each flagged section to determine the affects process adjustments have on the film product. Follow the property testing steps presented below:

1. Extract samples from the center portions of flagged or marked sections to ensure the film sample reflects stabilized process conditions. Number each sample (and record the sample number in Appendix E) for easy cross-reference back to the process conditions log (Appendix D).
2. Conduct testing on samples. Record test results in Appendix E.

3. Conduct a visual and tactile examination, comparing the recycled content product to the standard, original product(s). Inspect for differences of the recycled-content product from the original product, such as defects, evidence of bubbles, discoloration, and distinct differences in tearing. Record observations in Appendix E.

7.3 Post-Trial Evaluation

After each trial run, the trial and test results will indicate whether to continue per the original trial plan (documented in Appendix B and Appendix C), or to alter the plan for subsequent trials.

If the end-product is of acceptable quality and no problems were encountered in the trial, it may be best to proceed with the next planned trial in the original plan, or possibly redesign the plan to increase the planned recycled content amount for the next trial. If the original plan is changed, document the redesigned plan for the subsequent trials in a blank copy of Appendix B and C. The evaluation steps presented below may also be helpful in redesigning the next trials if changes are desired.

If the end-product is not acceptable, it is doubtful that increasing the recycled content will solve the quality issues. Instead, the plan should be redesigned to incorporate process adjustments, lower recycled content, or changes in the blend formulation to compensate for the recycled content resin. Follow the evaluation steps presented below to redesign subsequent trials:

1. Solicit input and comments from equipment operators on how the trial runs compare to standard products may be valuable in determining optimum machine conditions or material blends.
2. If possible, correlate the film properties with any equipment or process adjustments to determine optimum process settings for the blend. Cross-referencing the data logged in Appendix D and E will assist in this analysis. Note any observations and potential correlations in the product properties and processing conditions.
3. If the product is unacceptable, refer to in-plant (or outside) process knowledge and/or Table 3 for possible troubleshooting ideas. Do not continue to run higher recycled contents with the current virgin blend, because the tear strength (or other quality issue) will likely to continue to decrease.
4. Redesign the trial plan and document in a blank copy of Appendices B and C.

8.0 REFERENCES

*Applied Engineering Tools for Recycling:
Using Recycled HDPE Resins in Blown Film Applications*

1. Shah, Vishu, Handbook of Plastics Testing Technology, 1984.
2. Reference: Berins, Michael, Plastics Engineering Handbook of the Society of Plastics Industry, p. 102, 1991.
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4. Clean Washington Center. "A Tool For Targeting And Identifying Plastics Manufacturers For Conversion To Recycled Plastics". Seattle, Washington. January 1997.
5. The Plastic Bottle Institute. "Recommended Industry Specifications for Recycled HDPE." Technical Bulletin Number PBI 29-1993. Copyright: Society of the Plastics Industry, Inc. 1993.
6. Clean Washington Center. "Product Manufacturing: Screw Applications for Blowmolding" Best Practices in HDPE Recycling. BP-HDPE-3003. 1997.

APPENDIX A: LOGSHEET FOR BENCHMARK CONDITIONS

Pre-Trial Conditions	Data, Information or Measurement
Recycled HDPE properties	
Form (e.g., pellet or flake)	
Bulk density	
Color	
Grade	
Feedstock origin	
Polymer density	
Melt index	
Melt point	
Loose contamination	
Gel count	
Volatiles	
Pellet count	
Bulk density	
Blend formulation	
Mixing/blending process details	
Machine type / specifications	
Die size	
Gap width	
Screw length and L/D ratio	
Batch quantity and throughput	
Melt temperature	
_____ temperature	
Die/extruder pressure	
Air flow rate	
Pull speed	
Frostline height	
Screen change interval	
End-product property (specify)	

APPENDIX B: LOGSHEET FOR PLANNING TRIAL BLENDS AND PRODUCT TESTING

PLANNED **ACTUAL** Actual Trial Date _____ Trial Number _____

Trial Number	Recycled HDPE Content (%)	Virgin Resin Content (%)	Additives and Colorants (%)	Film Property Testing Requirements	Comments

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APPENDIX C: LOGSHEET TO PLAN EQUIPMENT SETTINGS

Mixing process and equipment: _____
 Extruder type and model: _____
 Die size _____
 Gap width _____
 Screw length and L/D ratio _____
 Process monitoring time intervals
 (e.g., every 10 minutes) _____

Equipment Settings	Trial Number				Comments
Mixing time					
Throughput rate (line speed)					
Melt temperature					
_____ temperature					
_____ temperature					
_____ temperature					
Die/extruder pressure					
Air flow rate					
RPM					
Pull speed					
Amperage					
Frostline height					
Blow-up ratio					
Screen change interval					

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APPENDIX D: LOGSHEET FOR PROCESS MONITORING

PLANNED

ACTUAL

Actual Trial Date _____ Trial Number _____

DATE: _____

TRIAL NUMBER _____

Mixing process and equipment: _____

Mixing time _____

Extruder type and model: _____

Die size _____

Screw length and L/D ratio _____

Gap width _____

Blow-up ratio _____

Comments _____

TRIAL AUDIT INFORMATION

ID #	Time	Film thickness	Melt Temp	Temp 2	Amps	RPM	Air Pressure	Air Flow Speed	Frostline Height	Die Pressure	Through-put rate	Comment
1	Stabilized/ Start-Up											
2												
3												
4												
5												
6												
7												
8												
9												

Comments: (e.g., screen cleanliness, etc.)

