

Guidelines for the Industrial Production of Biodegradable and Compostable Bags by an Existing Facilities in Georgia on the Example of Ltd. Zugo

Program Waste Management Technology in Regions Phase II

2019



This publication was produced by Caucasus Environmental NGO Network (CENN) for review by the United States Agency for International Development.

USAID Cooperative Agreement AID-114-A-17-00002

Prepared for:

Environmental Office

Economic Development Office

USAID | Caucasus

Prepared by:

Caucasus Environmental NGO Network (CENN)

27 Betlemi Street, 0105, Tbilisi, Georgia

Together with the international consulting company ENVITERRA P.C.

The authors' views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

Table of Contents

1. Introduction	5
1.1 General	5
1.2 Regulatory Issues	5
2. Fundamental Definitions/Glossary of Terms.....	6
3. EN 13432:2000 and ASTM D6400 Standards	13
3.1 General	13
3.2 Summary of IS EN 13432: “Compostable’ criteria”	13
3.3 ASTM D6400 Standard	14
4. Blown Film Extrusion	15
4.1 Process Glossary	15
4.2 General	16
4.3 The Process	16
4.4 A-B-A blown film.....	17
5. Zugo Company	18
6. General approach to transition process.....	19
6.1 Type of biodegradable polymers fit best with current processing technology	19
6.2 Type of biodegradable polymers suitable for certain applications	20
6.3 Adjustment of the properties of a given commercial resin for specific applications	20
6.4 Problems occurring on the production line	21
6.5 Adaptation of the production parameters	21
6.6 Functional properties of biodegradable products.....	22
6.7 Compostability/Biodegradability according to relevant standards.....	22
7. Processing of Bio-Flex® F 2110, and similar resins with existing Zugo equipment.....	22
7.1 General Recommendations	22
7.2 Processing PLA based raw materials	23
7.3 General Information for Bio-Flex® F 2110	24
7.4 Raw Material Storage.....	25
7.5 Drying.....	26
7.6 Purging Process before production	27
7.7 Equipment Settings.....	28
7.8 Purging after production	31
7.9 Shutdown.....	31
7.10 Storage conditions for films and finished products	34
8. Additives.....	34
8.1 General	34
8.2 Defining Needs	35

8.3 Enhancing processability	36
8.4 Coloring biopolymers	37
9. Research and Development (R&D)	37
9.1 Characterization of the solid-state physical properties of polymers available on the market	37
9.2 Characterization of the compositions and molecular structures of polymer materials available on the market	39
9.3 Modification of polymer properties using chemical routes	40
9.4 Modification of polymer properties using physical routes	40
9.5 Optimization of the processing of environmentally biodegradable polymers	41
9.6 Development support in industrial production processes	41
9.7 Research on functional properties	42
9.8 Biodegradation and Compostability testing	44
10. General Safety and Handling Precautions	45
11. References	46

1. Introduction

1.1 General

The current technical report has been prepared by ENVITERRA P.C. in accordance with the contract # SC/2018/536/WMTR II (7-12-2018) signed with CENN-Caucasus Environmental NGO. The report includes guidelines for the industrial production of biodegradable and compostable bags by an existing facility (**Ltd Zugo**), placed in Georgia.

The particular industrial facility currently produces plastic bags utilizing traditional non-biodegradable raw materials, such as HDPE and LDPE. The guidelines illustrated in this report, focus on the adjustment of the current production process in terms of producing biodegradable/compostable bags. Nevertheless, since the market of biodegradable raw materials and products is relatively new, a research and development plan is also proposed for optimizing future production line.

1.2 Regulatory Issues

According to national legislation (No 472 September 14, 2018 Tbilisi Georgia, On Approval of Technical Regulation on Rule of regulation of plastic and biodegradable plastic bags), there are specific conditions for the production, import and sale of bags, (article 4). More specifically, in the country of Georgia is prohibited:

- the production, import and sale of oxo biodegradable bags
- the production, sale and import of plastic bags with thickness less than 15µm (effected October 1, 2018)
- the sale/import of non-biodegradable/compostable plastic bags of all types and thickness (effected April 1, 2019)

Namely, only production, sales and import of biodegradable/compostable bags meeting the requirements of the Georgian Standards is permitted in Georgia.

Pursuant to Article 5 of the above Regulation, all bags produced/imported or sailed in the Country of Georgia must be verified with the European Standard EN 13432:2000: *“Requirements for packaging recoverable through composting and biodegradation – test scheme and evaluation criteria for the final acceptance of packaging”*. The latter Standard has been in place since 2000 and resonates the requirements stated in the Directive on Packaging and Packaging Waste (94/62/EC). More details about EN 13432:2000 requirements are provided in Chapter 3 of the current report.

2. Fundamental Definitions/Glossary of Terms

Before proceeding to any technicalities, the clarification of certain definition/terms referred to biodegradable/compostable bags is essential.

Biodegradable

Of all the environmental buzzwords “biodegradable” has perhaps been the most misused and the most difficult to understand. Because in the past there have been no guidelines or regulations, many products have called themselves biodegradable without any real justification. Unfortunately, the word biodegradable has frequently been applied to products that generally aren’t (such as detergents or plastics) and almost never used for products that really are (such as soap or paper).

The definition of biodegradable is that a material is capable of undergoing biological anaerobic or aerobic degradation leading to the production of CO₂, H₂O, methane, biomass, and mineral salts, depending on the environmental conditions of the process. An important role in biodegradation is played by microorganisms, which are present in the environment and fed mostly by organic waste. *However, unlike compostable, the term biodegradable means very little as everything is biodegradable given time. Thus, it is very important to specify the environment where biodegradation is intended to take place.*

Plastic biodegradability science and standards cannot be considered without an understanding of the definitions that shape the development of biodegradability standards and specifications. One key weakness of the term 'biodegradable' is that it does not contain any information on the location, timescale and extent of the decomposition process. Indeed, biodegradability is often defined in relation to the purpose or the conditions of interest, with separate standards and test methods having been developed for aerobic and anaerobic wastewater, freshwater environments and marine habitats. Several OECD (Organization for Economic Co-operation and Development) classifications for biodegradability exist, depending on biodegradation test performance and whether the term is taken to mean complete mineralization by microorganisms or an alteration in the chemical structure of a material due to biological activity.

There is also widespread public uncertainty concerning the exact meaning of this term. It is frequently conflated with 'compostable' and 'bio-based', with product labelling often a cause of additional confusion. When considering managed biodegradation processes, such as industrial composting, a sufficient definition of biodegradability can be reached with relative ease because the process conditions can be agreed upon and standardized. However, great care must be taken when attempting to define biodegradability within open environments, where a broad and complex range of physical and chemical conditions is typically encountered.

For purposes of this review, we define a biodegradable compound as one that is completely used as a source of carbon for microbial growth (based on the OECD definition of 'ultimate biodegradability'). Under aerobic conditions, the degradation process results in the production of carbon dioxide, water, mineral salts and new biomass. Under anaerobic conditions, methane and/or low-molecular-mass acids can also be produced.

Compostable

Composting is the process of breaking down organic waste by microbial digestion to create compost. Compost has many beneficial uses including improving and fertilizing soil. To go through a composting process, organic waste requires the right level of heat, water, and oxygen. In a pile of organic waste, there are millions of tiny microbes that consume the waste, transforming the organic materials into compost. In order to claim that a product is fully compostable, the product has to meet all the requirements in the European Norm EN 13432 and/or the US Standard ASTM D6400. Both specifications require that biodegradable/compostable products completely decompose in a composting setting in a specific time frame, leaving no harmful residues behind.

Bio-plastic

A general definition would be: “a plastic material that is biodegradable, bio-based or both”. The term in the primary definition is widely used in the plastics industry and less in the scientific community.

Alternative use 1: may also mean bio-compatible plastics (CEN/TR 15932).

Alternative use 2: natural plastic material. There are very few known bioplastics. A leading example is polyhydroxyalkanoates – natural thermoplastic polyesters.

Most plastics are based on a finite resource – crude oil. The consumption of crude oil is significantly higher than its regeneration, which inevitably means that this raw material will no longer be available at some point. Bio-based plastics offer an alternative here. Furthermore, consumers are becoming more environmentally-conscious in their consumer behavior, which means that sustainable bio-based materials are being increasingly implemented in place of conventional plastics.

In order for this to succeed, the plastics industry must provide information which enables the uncomplicated application and trouble-free processing of these bio-based plastics. There are certain gaps in the information concerning the processing of

bioplastics. Non-existent material datasheets or inadequate processing-relevant information impede the industrial processing of bioplastics and lead to non-optimal product results.

In principle, the range of available bio-plastics can already cover many fields of application today. However, processing problems often still arise, even if only small information gaps are apparent. In order to facilitate the transition from a petrochemical material to a suitable bioplastic, these gaps must be closed and the relevant information for the processors must be made available in an easily-accessible form.

Bio-based plastics are an extremely diverse group of plastics, exhibiting a tremendous range of characteristics similar to that of petroleum-based plastics. With very few petroleum-based plastic products meeting ASTM D6400, bio-based resins dominate the compostable plastic market.

There is no single classification system or methodology for characterizing bio-based plastics. Depending on the inquiry, bio-based resins can be grouped according to similarities in production feedstock, production processes, polymer performance characteristics, or end of life management options.

It is important to note that each manufacturer may make dozens of different variations, or grades of each resin type, catering to different end users and applications. For example, a manufacturer may have one resin line for thermoforming, one for injection molding, and yet another for sheet extrusion. In addition, resin lines may change depending on whether the final product requires food compatibility, compostability, etc. It is common practice for all of these types of bio-based plastics to be blended with colorants, petroleum-based plastics or plastic additives, or other bio-based plastics or plastic additives.

Bio-polymer

It is considered a polymer formed by living organisms. Biopolymers (=natural polymers) are crucial constituents of living organisms, including proteins, nucleic acids and polysaccharides. They are mainly polysaccharides (e.g., cellulose, starch and glycogen) and proteins (e.g., gluten, collagen and enzymes), although many other forms are also known, such as lignin, polyesters, etc.

Alternative 1: fully or partially bio-based polymer (CEN/TR 15932:2009)

Biodegradable plastics (Environmentally biodegradable plastics)

Meaning “plastics susceptible to biodegradation”. The degradation process of biodegradable plastics can include different parallel or subsequent abiotic and biotic steps; however, it must include the step of biological mineralization. Biodegradation of plastics occurs if the organic material of plastics is used as a source of nutrients by the biological system (organism).

Biodegradable plastics can be based on a renewable-biomass (i.e., starch) or non-renewable-fossil (i.e., oil) feedstocks processed in a chemical or biotechnological process. The source or process by which biodegradable plastics are produced does not influence the classification as biodegradable plastic. The biodegradation rate of a plastic item depends, in addition to the specific plastics formulation, also on the surface-to-volume ratio, thickness, etc.

Bio-based plastics

A general definition would be: “plastics based on biomass (excluding fossilized biomass)”. Plastics can be fully or partially based on biomass (= renewable resources). The use of renewable resources should lead to a higher sustainability of plastics. Although fossil sources are natural, they are not renewable and are not considered a basis for bio-based plastics. For defining the extent to which plastics are bio-based, see Bio-based carbon content. Bio-based materials are often referred to as biomaterials, although, in professional use the terms are not synonyms. The use of this term as a

synonym to the term bio-based plastics is inappropriate and should thus be discouraged.

Compostable plastics

Meaning: “Plastics that biodegrade under the conditions, and in the timeframe, of the composting cycle”.

Composting is a method of organic waste treatment conducted under aerobic conditions (presence of oxygen) where the organic material is converted by naturally occurring microorganisms. During industrial composting, the temperature in the composting heap can reach temperatures up to 70 °C. Composting is conducted in moist conditions. The composting process takes place over months. It is important to understand that biodegradable plastics are not necessarily compostable plastics (they can biodegrade over a longer time period or under different conditions), whereas compostable plastics are always biodegradable. The definition of criteria for compostable plastics is important because materials not compatible with composting can decrease the final quality of compost. Compostable plastics are defined by a series of national and international standards (i.e., EN-13432 and ASTM D6900), which refer to industrial composting. EN-13432 (see below) defines the characteristics of a packaging material to be recognized as compostable and acceptable to be recycled through composting of organic solid waste. EN 14995 broadens the scope to plastics used in non-packaging applications. These standards are the basis for a number of certification systems.

In Table 2.1, some of primarily used bio-polymers are illustrated (<http://www.bioplastics.guide>)

Table 2.1: Predominant Bio-polymers

Biopolymer	Feedstock	Raw material	Properties	Substitute for
------------	-----------	--------------	------------	----------------

Starch based	Corn, potato, wheat, tapioca	Starch	Low water vapour barrier Poor mechanical properties Bad processability Brittleness	Polystyrene (PS)
Cellulose based	Wood pulp	Cellulose	Low water vapour barrier Poor mechanical properties Bad processability Brittleness	Polypropylene (PP)
Polyhydroxyalkanoates (PHA) and (PHB)	Corn, potatoes, maize, tapioca, vegetable oils	Starch	PHAs – ranging from stiff, brittle to semi rubber-like. PHB has better oxygen barrier properties than both PP and PET, better water vapour barrier properties than PP, and fat and odor barrier properties that are sufficient for use in food packaging.	Polypropylene (PP) Polyethylene (PE)
Polylactic acid (PLA)	Corn (Major), sugar beet, potatoes, wheat, maize, tapioca	Lactic acid	High tensile strength and modulus. However, its brittleness and low crystallinity led to low thermal stability and limited applications.	Low-density and high-density Polyethylene (LDPE and HDPE) Polystyrene (PS) Polyethylene terephthalate (PET) Polypropylene (PP)

3. EN 13432:2000 and ASTM D6400 Standards

3.1 General

The EN 13432 standard: *“Requirements for packaging recoverable through composting and biodegradation – test scheme and evaluation criteria for the final acceptance of packaging”* has been in place since 2000 and resonates the requirements stated in the Directive on Packaging and Packaging Waste (94/62/EC).

This standard sets out the requirements for packaging recoverable through composting and biodegradation and describes a set of criteria for determining whether a material can be considered “compostable”. Nowadays, the terms “biodegradation”, “biodegradable materials”, “compostability” etc. are very common but frequently misused and a source of misunderstanding (as it was mentioned in Chapter 2). EN 13432:2001 resolves significantly this problem by defining the characteristics a material must own in order to be claimed as “compostable” and, therefore, recycled through composting of organic solid waste. The definition of the compostability criteria is very important because materials not compatible with composting (traditional plastics, glass, materials contaminated with heavy metals, etc.) can decrease the final quality of compost and make it not suitable for agriculture and, therefore, commercially not acceptable.

3.2 Summary of IS EN 13432: “Compostable’ criteria”

The Key tests and Pass / Fail criteria are summarized below

- Disintegration – Fragmentation and loss of visibility in the final compost (absence of visual pollution). Disintegration is measured in a pilot scale composting test according to EN-14045. The packaging sample is mixed with organic waste and maintained under test scale composting conditions for 12 weeks (3 months) after which time no more than 10% of material fragments are allowed be larger than 2 mm.

- Biodegradability – A measure of the actual metabolic, microbial conversion, under composting conditions, of the packaging sample into water, carbon dioxide and new cell biomass. Biodegradability is measured by the standard laboratory test method EN-14046 (also published as ISO-14855). Within a maximum of 6 months, biodegradation of the test sample must generate an amount of carbon dioxide that is at least 90% as much as the carbon dioxide given off from the control / reference material.
- Absence of any negative effect on the composting process. The latter is verified by a pilot-scale composting test.
- Low levels of heavy metals (Potentially Toxic Elements) and no adverse effect of the quality of compost produced. Upper limits, in mg/kg of dry sample, are: zinc 150, copper 50, nickel 25, cadmium 0.5, lead 50, mercury 0.5, chromium 50, molybdenum 1, selenium 0.75, arsenic 5 and fluoride 100.

The composted packaging material must not have adverse effect on the bulk density, pH, salinity (electrical conductivity), volatile solids, total nitrogen, total phosphorus, total magnesium, total potassium and ammonium nitrogen characteristics of the compost.

Each of the tests described above are undertaken according to internationally agreed methods of test, as specified in EN 13432. Independent laboratory test results are then compared with the strict pass / fail limits set in the standard. Only if a material passes every “compostable” test requirement is it proven to be “compostable”.

3.3 ASTM D6400 Standard

This specification covers plastics and products made from plastics that are designed to be composted under aerobic conditions in municipal and industrial aerobic composting facilities, where thermophilic conditions are achieved. ASTM D64000 is intended to establish the requirements for labeling of materials and products,

including packaging made from plastics, as “compostable in aerobic municipal and industrial composting facilities.”

The properties in this Standard are those required to determine if end items (including packaging), which use plastics and polymers as coatings or binders will compost satisfactorily, in large scale aerobic municipal or industrial composting facilities. Maximum throughput is a high priority to composters and the intermediate stages of plastic disintegration and biodegradation not be visible to the end user for aesthetic reasons.

4. Blown Film Extrusion

4.1 Process Glossary

L/D ratio: Length/Diameter ratio (refers to the screw)

Blow-up-ratio (BUR): The ratio of the bubble diameter to the die diameter

Compression ratio (CR): The ratio of the volume of the first turns of the channel of the screw (at hopper end) to the volume of the last turn of the channel (at the die end). This ratio lies usually between 1.5:1 to 4:1 depending upon the material.

Melt mass flow rate (MFR): Often also referred to as melt index, describes the ease of flow of plastics at a defined temperature. This property is measured by extruding a thermoplastic polymer melt at a specified temperature, under a pressure generated by a specific weight, through a capillary tube of known dimensions. The result is the extruded mass per unit of time, expressed in g/10 min. With a known melt density, it is possible to determine MFR from the **melt volume flow rate (MVR)**. In this test method the weighing of polymer extrudates is replaced by continuous measurement of the extrusion volume. The result for the MVR value is shown in cm³/10 min.

Adaptor: Die is attached to the extruder via an adaptor, also being used to change the direction of the flow.

LayFlat Bags: Two-dimensional bag (width x length) with bottom and/or side seals.

Gauge: The thickness of material. The higher the gauge, the thicker the material.

4.2 General

One of the most common methods of film manufacture is Blown Film (also referred to as the Tubular Film) Extrusion. The process involves extrusion of a plastic through a circular die, followed by "bubble-like" expansion. The principal advantages of manufacturing film by this process include the ability to:

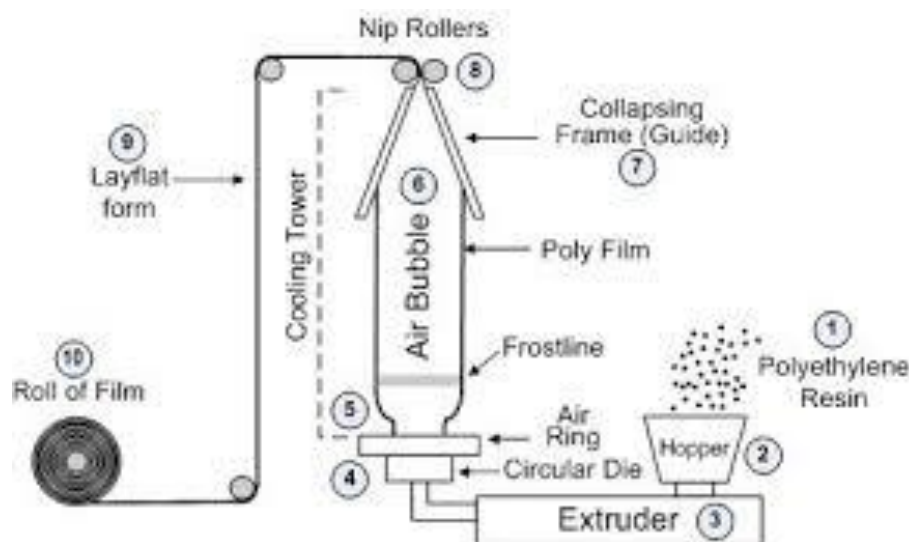
- Produce tubing (both flat and gusseted) in a single operation
- Regulation of film width and thickness by control of the volume of air in the bubble, the output of the extruder and the speed of the haul-off
- Eliminate end effects such as edge bead trim and non-uniform temperature that can result from flat die film extrusion
- Capability of biaxial orientation (allowing uniformity of mechanical properties)
- Blown Film Extrusion can be used for the manufacture of co-extruded, multi-layer films for high barrier applications such as food packaging.
- Blown Film Diagram

4.3 The Process

Plastic melt is extruded through an annular slit die, usually vertically, to form a thin walled tube (See also Photo 1). Air is introduced via a hole in the center of the die to blow up the tube like a balloon. Mounted on top of the die, a high-speed air ring blows onto the hot film to cool it. The tube of film then continues upwards, continually cooling, until it passes through nip rolls where the tube is flattened to create what is known as a 'lay-flat' tube of film. This lay-flat or collapsed tube is then taken back down the extrusion 'tower' via more rollers. On higher output lines, the air inside the bubble is also exchanged. This is known as IBS (Internal Bubble Cooling).

The lay-flat film is then either kept as such or the edges of the lay-flat are slit off to produce two flat film sheets and wound up onto reels. If kept as lay-flat, the tube of film is made into bags by sealing across the width of film and cutting or perforating to make each bag. This is done either in line with the blown film process or at a later stage.

Typically, the expansion ratio between die and blown tube of film would be 1.5 to 4 times the die diameter. The drawdown between the melt wall thickness and the cooled film thickness occurs in both radial and longitudinal directions and is easily controlled by changing the volume of air inside the bubble and by altering the haul off speed. This gives blown film a better balance of properties than traditional cast or extruded film which is drawn down along the extrusion direction only.



Picture 1: Typical Blown Film Extrusion illustration

4.4 A-B-A blown film

The A-B-A blown film machine consists of two extruders, normally of two different sizes. The most common ones today are the combination of a 45mm screw diameter together with a 55mm for T-shirt bag production. For garbage bags, normally a 55mm screw diameter with a bigger 65mm is used. In the A-A outer layer, normally 20% of CaCO_3 is used, with some additional of color masterbatch, LLDPE and a larger

percentage of HDPE. The B layer can be used with larger percentage of CaCO_3 with HDPE raw material. In-house recycled pellets can also be used to the mixture.

5. Zugo Company

According to the information provided by **CENN-Caucasus Environmental NGO** Network, **Zugo Company** is placed in Georgia and produces polyethylene bags, thickness of which varies from 2 to 100 μm .

The raw material is currently using for plastic bags production at the industrial facility refers to:

1. Polyethylene granular low pressure Marlex tr-144. Manufacturer Country Saudi Arabia
2. Polyethylene granular low pressure Hd7000f. Manufacturer Country Petro Chemical Iran
3. Polyethylene granular low pressure Md9007. (Calcium) Manufacturer Country: Maskom plastik Turkey
4. Polyethylene granular LLDPE low pressure. Manufacturer Country: Qatar Petrochemical Company Qatar
5. Polyethylene granular high pressure LDPE Manufacturer Country: Socar azerikimya Azerbaijan

As far as it concerns paint/dying substances, the following types are used:

- Sub2626 (one of the colors) Manufacturer: Maskom plastic Turkey
- M141624 (one of the colors). Manufacturer: Maskom plastic Turkey

For purposes of production A-B-A Extruder model: HDPE Film Co-extrusion & Blowing Machine Cambridge Machinery Co., Ltd, GQ-FB100 is used.

More Detailed description of the extrusion process and the effect of raw materials (resins) in the production parameters are provided in the following chapters.

As it was mentioned in the Introduction Chapter, Zugo currently produces plastic bags utilizing traditional non-biodegradable raw materials, such as HDPE and LDPE. Pursuant to the new Regulations (see Chapter 1), production process should be adjusted in terms of producing biodegradable/compostable bags with thickness greater than 15µm.

In this direction, the Company has identified a specific resin i.e. **Bio-Flex® F 2110**, produced by the German Company **FKuR Kunststoff GmbH**. The particular resin, as claimed by the manufacturer, is a biodegradable plastic based on PLA and other bio-polymers. Detail analysis of the particular resin is presented in the following Chapters.

Bio-Flex® F 2110 meets the requirements of the EN 13432 standard and ASTM D6400. It is therefore a certified compostable material. Bio-Flex® F 2110 has been also certified by United States Department of Agriculture (USDA) as a bio-based product.

6. General approach to transition process

Companies willing to set up a biodegradable plastics production facility or planning to modify existing processes for new biodegradable plastics applications (such as Zugo) will likely face one of the issues illustrated below, for which certain directions are given in this report.

6.1 Type of biodegradable polymers fit best with current processing technology

The solid-state physical properties of polymers available on the market is the critical parameter and should be thoroughly investigated. Thermal stability, softening temperature and mechanical properties of the biodegradable resins should be assessed. Furthermore, characterization of the biopolymer composition and molecular structure should be considered.

6.2 Type of biodegradable polymers suitable for certain applications

Selection of the appropriate biodegradable polymer for specific applications should be based upon the compositions and molecular structures of polymer materials available on the market. The thorough examination on this field will ensure product quality and biodegradability at the end of the product life cycle and also verify reproducibility of the supplied polymer material.

Such activities include:

- assessment of the properties of final products
- determination of impurities affecting processing of the material
- content and type of filler

The above activities will allow the Manufacturer (Zugo) to select the proper polymer material for specific applications and ensure that each polymer material delivered by the supplier meets the expected quality standards. He will also obtain insight on the specific storage (humidity, sunlight and temperature) and processing conditions for the selected polymer materials, as well as on the shelf life conditions for products based on those materials. Finally, he will obtain information in the non-recyclable fractions of the final product.

6.3 Adjustment of the properties of a given commercial resin for specific applications

Those adjustments can be made:

- By modifying the polymer properties using chemical routes.
- By modifying the polymer properties using physical routes.

Chemical routes may involve the application of chain extenders, introduction of functional groups and surface modification of the product (e.g., foil for better printing).

Physical routes may involve the formation of multicomponent materials through the addition of plasticizers, compatibilizers, fillers (preferably biodegradable) or blending with another biodegradable polymer.

All the above will allow to tailor the properties of the material to the specific manufacturing requirements.

6.4 Problems occurring on the production line

Optimization of processing of biodegradable polymers is necessary. That can be made by identifying the most appropriate temperature conditions in each of the production stages. Most of processing problems arise from the low thermal stability of bio-polymers. Namely, if the processing temperature is higher than the critical temperature, the material may undergo degradation, leading to a decrease in molecular weight and a drop-in viscosity.

Most bio-polymers have to be processed in lower temperatures than conventional resins (e.g. HDPE). Lowering the processing temperature or decreasing the residence time in the processing equipment will probably be necessary. Nevertheless, that is not always feasible, for example when the melting temperature of the material is too high. In that case, for a given resin, applied research is recommended, including the application of stabilizers, chain extenders, plasticizers or other routes that result in a decrease of the detrimental effects of degradation.

This will allow the utilization of traditional equipment with minor modifications without the need to invest in an entirely new production line.

6.5 Adaptation of the production parameters

Activities that will contribute to the development support of the industrial production processes will be necessary, allowing the reduction of the risk of failure and minimizing the costs of the product start-up stage.

Such activities may include:

- testing of the biodegradable plastic material in a laboratory scale
- pilot testing for new products
- on-the-spot adaptation of the technical parameters of the technology process.

6.6 Functional properties of biodegradable products

The functional properties of the product should be analyzed in concrete application areas. Such activities include the determination of the aging properties of polymer materials, barrier properties of polymer materials (gas permeation), thermo-mechanical properties of polymer materials, durability and shelf-life properties.

This will allow Manufacturer to offer a product on the market that meets the specific transport, storage, shelf-life and composting requirements.

6.7 Compostability/Biodegradability according to relevant standards

Biodegradation and compostability testing on the final product are essential. Collaboration with an accredited laboratory for performing tests according to EN-13432 Standard should be established. This will define the eligibility of the product with respect to certification receipt of the respective symbols or marks. Moreover, the Manufacturer will be able to inform final consumers about the compostability of the product.

7. Processing of Bio-Flex® F 2110, and similar resins with existing Zugo equipment

7.1 General Recommendations

All polymer processing lines (such as Zugo's) are designed to process a particular polymer and therefore it is critical to understand differences in the fundamental

polymer properties when introducing a new polymer into an equipment designed for another material. Because extrusion of bioplastics is complex, an experimental approach may be required to achieve optimum results (see R&D Chapter 9). Polymer density (both solid and melt), thermal conductivity, glass transition temperature and shrinkage are critical design parameters.

All bio-polymer producers recommend that the end-user should contact them before implementing any specific application, due to the complexity of the underlying legal requirements.

7.2 Processing PLA based raw materials

According to relevant literature and industrial experience, most processing problems with PLA and PLA based resins, stem from inadequate drying. PLA picks up ambient moisture very rapidly. Since PLA is a condensation polymer, the presence of even a very small amount of moisture during melt processing causes degradation of polymer chains and loss of molecular weight and mechanical properties.

PLA needs different degrees of drying depending on the grade and how it will be used. Usually, it has to be dried to below 250 ppm of moisture. Under 200 ppm is better because viscosity is more stable. PLA needs a dehumidifying (desiccant) dryer. Crystallized grades used to extrude sheet and film are dried at 50 - 70°C for 4 hr. Processes with long residence times or higher temperatures, need more drying, to less than 50 ppm of moisture. PLA requires crystallization so it will not clump together in a dryer.

PLA film can be extruded with a general-purpose screw, though some processors say output is better with a low-shear screw designed specifically for this resin. Some processors claim that some screws won't run PLA—polyolefin screws are the worst—and polyolefin extruders typically don't have enough drive power for PLA, either. Short, low-shear PVC screws reportedly are the best.

Some PLA manufacturers generally recommend a mixing section on the screw and a static mixer before the die for good melt uniformity. All temperatures in the extrusion system must be closely controlled, as excessive heat can be disastrous.

Roll handling equipment may need to be resized, and hoppers may need reinforcing to handle more weight. PLA has an average density of 1.24 g/cm^3 , a lot heavier than PE (0.94 g/cm^3). That means the same size roll of PLA film weighs a lot more than one of HDPE or LDPE.

Because PLA is denser than PE, chill rolls need to remove more heat from the same thickness of film. Cooling is hindered by the fact that the bio-resin conducts heat about 30% to 40% more slowly than PE.

7.3 General Information for Bio-Flex® F 2110

According to the producer (FKuR), using Bio-Flex® F 2110 to produce bags creates a finished product comparable to HDPE. In addition, bags made from Bio-Flex® F 2110 are very transparent and have an elegant surface gloss. Due to the high transparency, the bags can also be excellently colored. A coronary treatment for printing e.g. in offset or flexo-printing is not required for any of the Bio-Flex films. For printing, solvent-containing or water-based printing inks can be used.

The resin Bio-Flex® F 2110 possesses the following attributes:

- is similar to HDPE in terms of mechanical properties and feel. It is distinguished by a pearlescent gloss, high translucency and balanced mechanical properties of extensibility and stiffness.
- meets the requirements of the EN 13432 standard and ASTM D6400, and therefore, it is a certified compostable material.
- may be used as packaging material to be in contact with food according to EN 10/2011 and US FDA.

Some critical properties of Bio-Flex® F 2110, according to FKUR feedback are illustrated in Tables 7.1 and 7.2

Table 7.1: Mechanical Properties of Bio-Flex® F 2110

Tensile modulus of elasticity	730 [MPa]
Tensile strength	20 [MPa]
Tensile strain at tensile strength	> 300 [%]
Tensile stress at break	no break [MPa]
Tensile strain at break	no break [%]
Flexural modulus	680 [MPa]
Flexural strain at break	no break [%]
Flexural stress at 3.5 % strain	17 [MPa]
Notched impact strength (Charpy) RT	83 [kJ/m ²]
Impact strength (Charpy), RT	no break [kJ/m ²]
Density	1.27 [g/cm ³]
Bulk density	770 [kg/m ³]

Table 7.2: Thermal Properties of Bio-Flex® F 2110

Melt temperature	145 - 165 [°C]
Vicat A softening temperature	78 [°C]
Heat distortion temperature HDT B	n/a [°C]
Melt volume rate (MVR) (190 °C/2.16 kg)	3 - 4 [cm ³ /10 min]
Melt flow rate (MFR) (190 °C/2.16 kg)	3 - 5 [g/10 min]

Other properties: Insoluble in water

7.4 Raw Material Storage

The raw material is a biodegradable plastic based on PLA and other biopolymers. For that reason, it should be stored in an environment designed to minimize moisture

uptake and in a cool place at temperatures below 122°F (50°C). If pellets are exposed to a humid environment, they will absorb moisture from the air and even a low moisture content can start hydrolysis. Residual moisture content of more than 0.3% can result in fish eyes and/or pin holes during processing of blown film.

Generally, for the particular raw material, is recommended to be used within a time period of max. 6 months.

Usually, raw material pellets are shipped in moisture-proof metallic bags and are ready to use as supplied. They should be stored in a sealed container with desiccant in a dry location away from heat. Resin that is delivered in cartons or super sacks should be kept sealed until ready for loading into the blending and/or drying system. If the raw material is delivered in octabins, the latter should be used immediately or adequately sealed back up after use to avoid moisture uptake.

In the case of outside storage, if the product is supplied in boxes or other non-bulk containers, the unopened container should be brought into the extrusion production area and allowed to equilibrate for a minimum of 24 hours before opening to prevent excessive condensation.

7.5 Drying

FKuR recommends drying Bio-Flex® F 2110 at 60 °C for a period of 2 - 4 hours. An air flow rate of 1,8 m³ / hr - kg resin should be adequate. The particular resin can be successfully dried using most standard drying systems.

To prevent equipment corrosion, it is not recommended to dry or store hot resin in carbon steel vessels.

In-line drying is essential. It is recommended that the bio-polymer should be dried to a maximum of 250ppm of moisture as measured by a Karl Fischer method. A moisture level lower than 250 ppm will positively affect the stability of the biopolymer and will increase the viscosity stability over time at elevated temperatures.

Processes that have unusually long residence times or result in melt temperatures greater than 240°C, should only extrude the biopolymer at moisture levels less than 50 ppm for maximum retention of molecular weight and physical properties.

The resin should not be exposed to atmospheric conditions after drying. The package should be kept sealed until ready to use and promptly dry and reseal any unused material.

To prevent issues with pellet bridging, sticking or melting, the drying system should be verified to ensure temperature control is adequate during operation as well as during regeneration cycles since valve leakage is common in many systems.

7.6 Purging Process before production

Most bio-polymers are not compatible with a wide variety of resins and special purging sequences should be followed. Prior to introducing the biopolymer into the processing system (extruder), the latter should be properly cleaned and purged to prevent any polymer cross contamination.

First of all, the hopper (feed) system should be vacuum out in order to avoid any contamination. Generally, we should ensure that the feeding & blending equipment is thoroughly cleaned and free from dust and contamination and all metal magnets have been wiped clean. Furthermore, dust and granules must be completely removed from all hang-up areas such as elbows transitions drain ports, filters and slide gates.

It is critical to clean the material handling system of high molecular weight HDPE to assure that this material does not inadvertently feed into the extruder during or after the purging process. It is critical that all drying and conveying/receiving systems be free of all HDPE and vacuumed to ensure that there is no remaining polymer dust, before adding bio-polymer. HDPE will not melt at Bio-Flex® F 2110, operating temperatures and will block screens, if it is present in the system.

FKuR recommends that the extruder should be purged with low viscosity - melt LDPE (MFR approx. 4 - 6 g / 10 min) using temperature settings that are proposed for production (biopolymer temperatures, not HDPE temperatures -see below), providing that all temperature zones are working correctly. The purging time should be approximately 10 - 20 minutes.

As a general rule, purging for at least 5-7 x average residence time is recommended, letting the system empty as much as possible.

After the aforementioned procedure, the extruder should be turned off and we should completely clean all hoppers, elbow, slide gates, dryers, hopper loaders bins, hopper loader filters and material conveying lines of residual resin pellets, flake, dust, and floss. Then, bio-polymer is ready to be fed into material handling system.

For better results, a second purge stage for a minimum 5-7 x the average residence time, using solely Bio-Flex® F 2110, is recommended. After that time, we should change screen pack when it becomes obvious that primarily Bio-Flex® F 2110, is exiting the die. Be sure to flush screen pack completely during the change. Screen pack should be between 40- 125 mesh for optimal performance. The lower mesh screen will result in reduced melt temperatures exiting the die.

At the completion of a trial run, all Bio-Flex® F 2110, from the extrusion system should be purged, using a moderate to low melt index resin that processes well between 400 and 450°F (205-230°C), initially using the Bio-Flex® F 2110, temperature settings and extrusion rates.

7.7 Equipment Settings

For blown film extrusion process, the following equipment settings are recommended:

1. Temperature Profiles

Zone 1 170 [°C]

Zone 2 170 [°C]

Zone 3 170 [°C]

Zone 4 170 [°C]

Adapter 175 [°C]

Lower die 175 [°C]

Upper die 175 [°C]

Water jacket (feed) 35 [°C]

Mass temperature max. 190 [°C]

2. Resin Specifications

Density 1.26 [g / cm³] (Bio-Flex® F 2110)

Bulk density 758 [kg / m³] (Bio-Flex® F 2110)

MFR (190 °C / 2.16 kg) 3 - 5 [g / 10 min]

3. Other Settings

Die gap 0.8 - 1.4 [mm]

Die diameter up to 400 [mm]

Blow film ratio 2.5 - 4

Screws with L/D ratios from 24:1 to 32:1 and compression ratio of 2.5:1 to 4:1 will be sufficient for normal raw material processing.

Generally, all films made with bioplastics are slightly more sensitive to processing conditions such as temperature profile, die gap and blow up ratio.

The viscosity of bioplastics is much more sensitive to changes in temperature than other thermoplastics such as polyethylene. Therefore, when making temperature adjustments to fine tune a process, much smaller changes are required to get the desired response. As a general rule, it is best to make one half of the temperature change than you would when processing polyethylene. In practice, melt temperature must be continually monitored.

For temperature profile, the recommended from the manufacturer temperatures should be implemented. In some cases, gel particles or die lines may appear. When those phenomena are observed, a small rise in temperature is essential. Nevertheless, any temperature rise should be implemented with caution and in small steps (e.g. maximum 5 °C per step) and the temperature must not exceed 190°C.

It is essential to use sufficient cooling for extruder and bubble, a dual lip air ring and/or inner bubble cooling system with chilled air, as the melt is relatively soft when emerging from the die.

It should be mentioned that **Bio-Flex® F 2110**, is based on PLA. The PLA possess relatively high density of 1.24 g/cm³ (0.94 g/cm³ for polyethylene) and viscosity of 3460 Pa-s at 150 °C (115 Pa-s at 151 °C for polyethylene) and thus can pose a potential problem for current infrastructure of film manufacturing. Most extrusion screw systems are designed for processing of materials with much lower viscosity at their melt temperature. If the motors driving the screws are operating at near capacity, the added stress of processing a much denser material may cause the system to “jam-up” and/or burnout the motors of the extrusion system. Additives and copolymers may provide a solution, as these materials tend to have different melt flow properties, particularly melt temperatures, and may be easier to process (see also Chapter 8).

At the beginning of the blown film process, pulling speed has to be slow because of the cooling effect. When the process become stable, speed can be increased slowly, but usually, should not exceed 150r/min.

All metal parts in the extrusion process that are subjected to stagnant flow areas with molten polymer should be constructed of stainless steel to minimize corrosion. This includes melt pump and filter assemblies and some transfer lines. Furthermore, bio-polymer should not be left in the extruder, polymer filter, polymer transfer lines, dies or any other part of the extrusion system at recommended or higher melt temperatures for extended periods (see also par. 7.8).

7.8 Purging after production

FKuR recommends to purge out the extruder with an LDPE, MFR 0.4 -2.0 [g / 10 min] when the production cycle has finished. For other resins, the same process is usually acceptable. No material should remain in hot condition and for long time within the extruder, since that will lead to material degradation. The latter may lead to equipment corruption.

7.9 Shutdown

1. A thermal decomposition product of any PLA based bio-polymer is acetaldehyde. Thermal decomposition products also include carbon monoxide and hexanal, all of which exist as gases at normal room conditions. These species are highly flammable, easily ignited by spark or flame, and can also auto ignite. For polyesters such as PLA, thermal decomposition producing flammable vapors containing acetaldehyde and carbon monoxide can occur in almost any process equipment maintaining PLA at high temperature over longer-than-normal residence times (e.g. extruders, pipe lines and adapters).

As a rough guideline based upon some practical experience, significant decomposition of PLA will occur if polymer residues are held at temperatures above the melting point for prolonged periods, e.g., in excess of 24 hours at 175°C, although this will vary significantly with temperature.

2. Under normal extrusion operations, the residence time of the molten polymer is on the order of minutes and therefore no thermal decomposition is expected when the recommended set temperatures are used. It is not recommended to shutdown extrusion or transfer lines while keeping them heated for extended times with PLA still inside the equipment. If equipment is to be kept at temperatures above 175°C for more than 3 or 4 hours, it is recommended to purge the film extruder with 100% LDPE. Leaving any starch-based resin (like Bio-Flex® F 2110,) in the extruder during shutdown and startup may cause it to burn and delay normal startup on the next use.
3. Minimize holding time of PLA inside of process equipment in the molten state. Clear equipment rather than keeping on hold for extended periods at elevated temperatures above the melting point (>175°C). Clear/purge materials to a safe location in case decomposition continues. Be aware that the rate of thermal decomposition increases rapidly with increasing temperature.
4. Purge lines and equipment with nitrogen to keep the products of PLA decomposition out of the flammable range.
5. Purge the gases to a safe location. Be mindful of the hazards of asphyxiation associated with the use of inert gases.
6. Be aware that the introduction of air into a system that has been kept under heating conditions can lead to potentially explosive conditions and should be avoided.
7. Treat line and equipment opening with special caution, particularly if they contain PLA which has been held above 175 °C for an extended period, since highly flammable decomposition gases may auto ignite if above about 175 °C or which can ignite and burn as easily as methane even when cooled below 175°C. Use of flammable gas detection meters is strongly suggested as part of preparation for line and equipment opening and clearing procedures.

8. Be sure to keep spark and flame producing equipment out of the process areas until proper clearing of the line has been completed
9. Use proper maintenance tools when clearing or working around equipment containing PLA or PLA decomposition products. Consider use of explosion meters, non-spark producing tools, fire resistant clothing and foot wear that is non-spark producing, depending on the nature of the work being performed. Clothing that will melt and stick to the skin when subject to flame should also not be used in a work place where flammable vapors or liquids can be present.
10. Design piping to minimize leaks with leak-resistant gaskets like spiral wound or metal rings. Use low surface area insulation in areas where leaks might be expected. Use temperature limiting heat tracing to avoid excessive hot spots.
11. Train both operation and maintenance personnel on the hazards of processing PLA at elevated temperatures and particularly the special hazard of thermal decomposition for prolonged periods. Make sure operating and maintenance procedures contain adequate precautions for these hazards.
12. During normal operations, there often are times when the extrusion system needs to be stopped to perform maintenance on part of the line. If this time is short (less than 2 hours) and the system temperatures are in control at normal PLA processing temperatures of less than 240°C, the risk of an unplanned event due to thermal decomposition is very low and purging of the system is not necessary. However, thermal degradation, resulting in a loss of molecular weight accompanied by a drop in viscosity will occur. Upon restarting the line, it is imperative that all safety precautions for starting a line with low molecular weight polymer be followed. This includes keeping away from the front of the extrusion die and keeping all exposed skin protected from hot molten polymer. Anyone in near the extrusion die should also wear full protective face shield as low viscosity polymer can spray from the front of the die upon start up

7.10 Storage conditions for films and finished products

Films on rolls and finished products made from Bio-Flex (or other bio-polymers) must be stored dry and cold. It is recommended to wrap goods in black PE inliners to protect them against moisture and UV radiation. In any case, FKUR recommends to use films on rolls and products as soon as possible and not to store them for a time period of more than 6 months.

Storage time depends on processing parameters and of climate conditions in the respective area (e.g. Georgia). Because of these essential and complex interacting parameters, FKUR cannot give any shelf life guarantees for finished goods. The conditions mentioned above depend on experiences of their customers. The Manufacturers of bio-polymers recommend that the consumer has to perform his own tests with respect to the time period final products can be stored.

8. Additives

8.1 General

Bio-polymers are much like other plastics in that they need help from additives to address inherent weaknesses in processability and physical properties. Some weaknesses stand out particularly in the current generation of biopolymers. On the performance side, they tend to be limited in impact strength and heat resistance. On the processing side, they often need enhancements in melt strength and sometimes thermal stability or lubricity to overcome a tendency to stick to processing equipment.

Color concentrates, slip and anti-block agents etc. can be added as additives in BioFlex resins, as FKUR claims. In BioFlex MSDS, is also mentioned that the particular resin already contains additives. The main point of concern is that, since the exact chemical composition of Bio-Flex® F 2110, is not known, the % participation of additives in the masterbatch should be recommended by FKUR. Another key issue is that, some additives may be inappropriate for extrusion with Bio-Flex® F 2110, (e.g. hygroscopic

or hydrated salts) and may lead to severe biopolymer molecular weight degradation and property loss.

Three levels of additives for biopolymers are currently being explored worldwide:

- Conventional additives that have no adverse effect on health or environment and do not compromise biopolymers compliance with compostability standards.
- Renewable additives derived from natural sources, but not necessarily biodegradable, for use in durable products.
- Additives that are both renewable and biodegradable, mostly for single-use or short-lived products.

When additives are added to biopolymers and other plastics intended for composting, they must meet standards for compostable plastics such as ASTM D6400 and its European Union counterpart, EN 13432.

Key issues for improved physical properties of biopolymers include impact modification, heat resistance and barrier performance. Secondary issues include UV, antioxidant, and anti-fogging properties.

8.2 Defining Needs

Some biopolymer producers are offering their materials uncompounded, requiring customers to incorporate additives, while others offer fully compounded products that may only need addition of colorant. Some of the latter suppliers were reluctant to discuss the additives they use in their compounds or denied that they are particularly necessary.

On the other side there are producers, which sell mainly unmodified PLA and they are quite clear about the types of additives needed for optimal processing of PLA and for improving its end-use properties. Antistats are also used in PLA films, as are a variety of processing aids that can reduce die pressures and motor loads on extruders. Also

important are rheology modifiers in the form of polymer chain extenders that improve melt strength in foam and blown film.

Starch-based biopolymers (such as PLA) from certain Companies are sold as finished compounds with additives already incorporated.

Additives required by starch-based biopolymers generally include flow additives and melt-strength enhancers. There are certain products which reportedly add melt strength and flexibility to these resins and allows them to be used in blown film.

Akin to PE film resins, some producers are adding talc and calcium carbonate fillers, as well as vegetable-based slip and anti-block agents to PHA to reduce cost and modify film stiffness and toughness.

Anti-stats are also used in PLA films, along with a range of processing aids that can reduce die pressures and motor loads on extruders. Rheology modifiers in the form of polymer chain extenders improve melt strength in blown film. Impact modification is important due to PLA's inherent brittleness, along with use of antioxidants and UV stabilizers.

8.3 Enhancing processability

Several companies have developed conventional and bio-based additives to enhance processing of biopolymers such as PLA, PLA blends and starch resins. Some of them, for example, offer anti-block, and mold-release agents. Many of these emerging biopolymers are tacky and tend to stick to themselves and to metal surfaces during processing. Consequently, the Market offers a range of additives to control or eliminate sticking for improved processing and handling efficiencies.

Low melt strength, which can hinder extrusion, is another common limitation of PLA and other biopolymers. Recognizing this need, some producers suggest the use of additives, which reportedly can double the melt strength and extensibility of PLA at a 4% loading while maintaining transparency.

8.4 Coloring biopolymers

In addition to traditional pigments that can be used in biopolymers, bio-derived colorants are now available from several companies. Many of those color concentrates are derived mainly from plants and include red, orange, yellow, and green, with blue in the final stages of development. These colors are very earthy and organic-looking, and some have excellent clarity, though their lightfastness is not as high as traditional colorants. Various biopolymers can serve as carriers for these masterbatches.

As a final conclusion, many of those issues can satisfactory resolved by implementing an R&D plan, as illustrated in Chapter 9.

9. Research and Development (R&D)

Since the bio-polymer market is relatively new, the conduction of an R&D program is highly recommended. Note that all the properties of the commercially available biopolymers (including Bio-Flex® F 2110,) are not to be considered as specifications.

An overview of the research and development activities to be taken into account when considering the development and production of environmentally biodegradable plastics products is presented in this Chapter.

9.1 Characterization of the solid-state physical properties of polymers available on the market

A. Select a polymer with appropriate thermal stability features

The research activity may include analysis of the thermal stability (degradation temperature) of single or multi-component materials (e.g. by thermogravimetric analysis, from Room Temperature to 900°C in an inert atmosphere or air). This way, we may obtain relevant information on the temperature range in which the polymer can be safely processed.

B. Obtain insight on the thermal degradation behavior of a polymer

The research activity may include analysis of the thermal stability and mass spectrometry of volatiles (by TGA-MS, from RT to 900°C) and changes in molecular weight (GPC). This way, we may obtain relevant information on degradation fractions released by the polymer during thermal treatment.

C. Assess the specific softening temperature of a polymer

The research activity may include analysis of thermal transitions: glass, crystallization and melting transitions by determination of the transition temperatures and of the respective specific heat increments; crystallization and melting enthalpies by differential scanning calorimetry in the temperature range of -100°C to 250°C with liquid nitrogen cooling.

This way, we may obtain relevant information on the processing temperature window, the setup of processing parameters and the temperature range of use.

D. Verify the mechanical properties of the polymer material

The research activity may include evaluation of mechanical properties at room temperature i.e. elastic modulus, stress and strain at yield and break by tensile testing with statistical analysis of the results. This way, we may obtain relevant information on the material performance in terms of strength, rigidity and deformability.

E. Verify the thermo-mechanical behavior of the polymer material in specific conditions

The research activity may include determination of the viscoelastic relaxations by dynamic mechanical analysis in single - or multi-frequency modes in the temperature range of -150°C to 250°C. This way, we may obtain relevant information on long-term behavior of the material (potential aging) and on material response to vibrational strain.

F. Determine if a fraction of the polymer is crystalline

The research activity may include structural analysis of the crystal phase (by wide angle X-ray powder diffraction). This way, we may obtain relevant information on the effect crystallinity on the solid-state material behavior

9.2 Characterization of the compositions and molecular structures of polymer materials available on the market

A. Obtain insight on the composition of insoluble or cross-linked materials

The research activity may include determination of the solid-state properties using infrared spectroscopy (FTIR, Fourier Transform Infrared Spectrometer). This way, we may obtain relevant information on the type of polymer and functional groups present in the polymeric material

B. Determine if there is any filler in the material

The research activity may include characterization of the material solubility and determination of the polymer percentage in the plastic. This way, we may obtain relevant information on the content and type of insoluble filler.

C. Obtain insight on the composition of the soluble fraction of the material

The research activity may include characterization of the polymer in the plastic by NMR (nuclear magnetic resonance) spectroscopy. This way, we may obtain relevant information on the chemical structure of the selected polymer (statistical content of particular units).

D. Determine if your polymer material has suitable molecular weight for the specific application

The research activity may include evaluation of the polymer molecular weight using the GPC technique (gel permeation chromatography). This way, we may obtain relevant information on the molar mass, molar mass dispersity as well as branching degree

E. Identify which organic additives the plastic contains

The research activity may include analysis of the additives using mass spectrometry (LCMS-IT-TOF, hybrid mass spectrometer). This way, we may obtain relevant information on the chemical structures of the organic additives

9.3 Modification of polymer properties using chemical routes

A. Obtain insight on the ultimate properties and processing parameters

The research activity may include determination of the physical properties of polymeric materials. This way, we may obtain relevant information on the mechanical properties, viscosity, flow curves, gas permeation and flammability of the material.

B. Identify how to change properties of the commercially available material

The research activity may include modification of polymers to achieve specific properties, i.e., crosslinking of polymers for better solvent resistance. This way, we may obtain relevant information on the development of tailored material according to specific requirements

C. Understand how to achieve special surface properties

The research activity may include modification of polymers to achieve specific properties, i.e., increased polymer surface polarity for better printability, adhesion and thermal and oxidative stability. This way, we may obtain relevant information on the development of tailored surface material properties for specific requirements

9.4 Modification of polymer properties using physical routes

A. Change properties by adding low-molecular weight additives

The research activity may include modification of the properties of a particular polymer by adding low-molecular weight additives, e.g., plasticizers, chain extenders, stabilizers, or by blending with small quantities of another polymer to achieve the

desired properties. This way, we may obtain relevant information on the development of a tailored material according to specific requirements.

B. Change properties by blending with other polymers

The research activity may include blending two polymers over their full concentration range to give the desired properties, achieved by modification of the interface and compatibility of the components. This way, we may obtain relevant information on the development of tailored material according to specific requirements

C. Change properties by adding fillers

The research activity may include preparation of composites based on a polymeric matrix with tailored properties via modification of the interface. This way, we may obtain relevant information on the possibility to lower overall material costs by adding low-cost additives with marginal or no changes in required properties

9.5 Optimization of the processing of environmentally biodegradable polymers

A. Optimize the processing route for a particular polymer material

The research activity may include determination of the processing parameters of selected polymer materials. This way, we may obtain relevant information on the parameters of the new production line to be installed or the technology procedure manual for the current production line

9.6 Development support in industrial production processes

A. Determine whether current production line will be capable of processing the selected polymer material for film production

The research activity may include laboratory scale production of films, including research on processing and blending, production of masterbatches, production of

specimens for material testing and recording of the rheological properties. This way, we may obtain relevant information on the pilot conditions for material processing

B. Determine whether current production line will be capable of processing the selected polymer material for flexible packaging production

The research activity may include laboratory scale production of flexible packaging. This way, we may obtain relevant information on the behavior of the melting and film blowing processing properties of the product you intend to form.

C. Identify the most appropriate processing parameters

The research activity may include support of pilot production on-site. This way, we may obtain relevant information on the processing parameters that allow minimization of quality and cost risks.

D. Obtain insight on possible changes that might occur in the physical properties of the material after processing

The research activity may include controlling the mechanical properties of the product during the production process, i.e., mechanical property measurements (e.g. tensile tester). This way, we may obtain relevant information on the probability of degradation and crystallization in the processing and product storage stage as well as the additives we should consider

E. Verify whether the material molecular properties change during processing

The research activity may include controlling the molecular weight of the product after the production process. This way, we may obtain relevant information on the degree of degradation of the material during processing

9.7 Research on functional properties

A. Obtain insight on product durability under specific storage and usage conditions

The research activity may include Xenotest method used to determine the material behavior in natural conditions. This way, we may obtain relevant information on product shelf life and lifetime

B. Obtain insight on the ecological impact of the material

The research activity may include determination of the total organic carbon and bio-based content of the polymer materials. This way, we may obtain relevant information on the concentration of renewable carbon in selected material.

C. Understand how gases are trans-mitted through the product

The research activity may include testing the permeability of water vapor, oxygen and carbon dioxide. This way, we may obtain relevant information on possible applications of the product in downstream industries (i.e. industries or consumers utilizing our products)

D. Identify possible applications for selected materials and products based on them

The research activity may include:

- Determination of tensile properties (stress at break, elongation at break, modulus of elasticity, etc.)
- Determination of tear resistance
- Determination of impact resistance using the free-falling dart method

This way, we may obtain relevant information on the mechanical properties for specific applications, such as durability.

E. Understand more about closure and sealing opportunities of your material or product

The research activity may include:

- Sealing properties (max load at break, sealing resistance, etc.)

- Hot-tack seal testing

This way, we may obtain relevant information on how and under which conditions the tested material seals.

F. Obtain insight on the physical/chemical properties of the product

The research activity may include DSC (differential scanning calorimetry) and FT-IR (infrared spectroscopy). This way, we may obtain relevant information on the application temperature range of our product and its suitability for specific applications

G. Verify the presence of dangerous impurities

The research activity may include testing of the monomer content in plastic materials and of the emission of volatile substances. This way, we may obtain relevant information on the processing risks leading to difficulties in certification.

9.8 Biodegradation and Compostability testing

A. Verify how quickly the material disintegrates in compost

The research activity should include disintegration testing under laboratory conditions: preliminary tests of biodegradation on the packaging material using simulated composting conditions in a laboratory-scale test according to relevant Standards. This way, we may obtain relevant information on the compostability potential of the material.

B. Understand how well your material biodegrades (1)

The research activity should include degradation under laboratory conditions: hydrolytic degradation test in water or a buffer solution (degradation tests of biodegradable polymers in simple aging media to predict the behavior of the

polymers). This way, we may obtain relevant information on the degradation potential of the material in specific media.

C. Understand how well your material biodegrades (2)

The research activity should include degradation and compostability testing under laboratory conditions: laboratory degradation in compost using a respirometry test (according to EN ISO 14855-1:2009 - Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions - Method by analysis of evolved carbon dioxide - Part 2: Gravimetric measurement of carbon dioxide evolved in a laboratory-scale test)

This way, we may obtain relevant information on the compostability potential of the material

D. Obtain feedback on whether your product might receive the necessary certification and labels

The research activity should include (bio)degradation and compostability testing at composting facilities (e.g. tests of biodegradable material in an industrial composting pile). This way, we may obtain relevant information on the conditions necessary for getting the product certified and obtaining the right to mark it with a compostability label.

10. General Safety and Handling Precautions

All safety precautions normally followed in the handling and processing of melted conventional raw materials for plastic bags production should be followed for bio-polymers.

Melt processing and the variability of those conditions may result in minor decomposition. Lactide, a non-hazardous gaseous irritant, could be a minor by-product of the bio-polymer melt processing. Appropriate air testing should be

completed to ensure an acceptable Threshold Limit (depending on local Regulations) is maintained. The use of process area point source remediation measures such as monomer fume hoods or exhausts near the die or over any open vent ports are typically recommended.

At ambient temperatures, Bio-Flex® F 2110, is considered non-hazardous (see MSDS). When handling resin at room temperature avoid direct skin and eye contact along with conditions that promote dust formation. For further information, consult the appropriate MSDS.

As with any melted waste, molten resin waste should be allowed to cool before being placed into any waste container to minimize fire risks.

11. References

1. PT: Plastics Technology (<https://www.ptonline.com>)
2. NatureWorks (<https://www.natureworkslc.com/Products>)
3. NatureWorks. "NatureWorks Presentation." Lecture, April 15, 2010.
4. Bioplastics Guide (<http://www.bioplastics.guide>)
5. Plastemart (<http://atozplastics.com/upload/Literature/Additives-aid-biopolymers-overcome-limitations-improve-properties.asp>)
6. Innovative Value Chain Development for Sustainable Plastics in Central Europe (PLASTiCE) (2014). The roadmap for Action – From science to innovation in the value chain. CENTRAL EUROPE Programme (co-financed by the ERDF). (www.plastice.org)
7. Technical report CEN/TR 15932 (2010): Plastics - Recommendation for terminology and characterization of biopolymers and bioplastics, European Committee for Standardization, Brussels, March 24, 2010.

8. Handbook of Biodegradable Polymers (2005). Rapra Technology Limited, 1st ed., United Kingdom
9. Dana Adamcová, Jakub Elbl, Jan Zloch, Magdalena Daria Vaverková, Antonín Kintl, David Juříčka, Jan Hladký, Martin Brtnický (2017). Study on the (bio)degradation process of bioplastic materials under industrial composting conditions. *Acta universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, Vol. 65

(<https://doi.org/10.11118/actaun201765030791>)
10. Sonal S. Karkhanis, Nicole M. Stark, Ronald C. Sabo, Laurent M. Matuana (2017). Blown film extrusion of poly(lactic acid) without melt strength enhancers. *Journal of Applied Polymer Science* (DOI: 10.1002/app.45212)
11. LyondellBasell Industries (2018). How to solve blown-film problems. Houston, USA. (<https://www.lyondellbasell.com/>)
12. European Bioplastics. "Bioplastics at a Glance." <http://www.europeanbioplastics.org/index.php?id=182> (accessed March 30, 2011).
13. ASTM Standard D6400, 2004. "Standard Specification for Compostable Plastics." ASTM International. West Conshohocken, PA, 2004. DOI: 10.1520/D6400-04. (www.astm.org)
14. ASTM Standard D6866, 2010. "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis." ASTM International.
15. EN 13432:2000 Packaging - Requirements for packaging recoverable through compo-sting and biodegradation
16. Bio-Flex® F 2110, Material Safety Data Sheet (MSDS).

(<https://fkur.com/en/brands/bio-flex-3/bio-flex-f-2110/>)

17. Bio-Flex® F 2110, Technical Data Sheet (TDS)

(<https://fkur.com/en/brands/bio-flex-3/bio-flex-f-2110/>)

18. Bio-Flex® F 2110, Processing Guide (<https://fkur.com/en/brands/bio-flex-3/bio-flex-f-2110/>)