Production of Oriented Polylactide (OPLA) Film on Equipment Designed for Producing Oriented Polypropylene (OPP) Film

The increased market acceptance of oriented films made from polylactide has created a renewed interest in understanding the machinery requirements for producing OPLA film and more importantly the suitability of existing orientation assets to produce OPLA films.

While PET and PA lines can be used with minimal modification to produce OPLA films, by far the largest number of orientation lines available worldwide are those which were designed to produce OPP films. Unfortunately, these lines have a number of significant design limitations, which would require modification before attempting to produce OPLA films. These modifications can have significant expense both in terms of capital equipment and downtime of the line required for installation.

Raw Material Handling

Almost no OPP manufacturing line is equipped with desiccant bed dryers designed to dry down to less than 250 ppm of moisture. In addition, and perhaps more importantly, once the material is dried, it needs to be conveyed to the extruder with dry air to keep the resin from regaining moisture. All the blending and holding hoppers also need to be sealed to keep a dry environment for the resin. Drying of PLA is necessary to produce OPLA film.

Extrusion

While not ideally suited for melting PLA, most extruders designed for processing PP would be able to melt and process PLA at some level with acceptable performance. Typically, the higher shear rates and longer L/D required for PP are unnecessary for PLA and lead to higher than desired melt temperatures upon exiting the extruder. Therefore, extruders designed for PP will generally be rate limited at a much lower rate than PP due to excessive shear heating and melt temperature. Long term production of OPLA film would require a change in screw design. While not absolutely necessary for short experimental runs, long term commercial production of OPLA film at economically viable levels for a given extruder would require a screw change to one designed to process PLA.

Filtering

PLA is highly filtered during its manufacturing process to remove gels that could cause disruption in the orientation process. Since the chemical nature of PLA is such that gels are unlikely to form during extrusion, high filtration at the extruder is unnecessary and in fact can be harmful. The large candle filters typically used in many OPP extrusion lines add significantly to the residence time of the PLA at melt temperature. In addition, the increased back pressure generated on the screw increases the melt temperature of the PLA. The combination of increased melt temperature and residence time is detrimental to PLA in many ways. First, it can lead to a loss of molecular weight of the resin, which will reduce melt strength and possibly reduce properties. Even without a loss in molecular weight, the increased melt temperature itself would cause a loss in melt strength and lead to difficulty in primary sheet casting. Finally, the yellowness index of the material can increase to unacceptable levels with long residence times and increased melt temperatures. The replacement of a large candle type gel filter with a simple screen changer equipped with screens in the range of 80 -120 mesh is necessary to produce OPLA.

Metering

The metering gear pump used to control the flow of polymer to the die from the extruder can generally be used for processing PLA for short term experiments. However, for long term production, it is important that the material of construction be suitable for PLA. Since metering pumps use the polymer melt to lubricate the pump bearings, it is critical that they be resistant to corrosion. Once again, replacement of pumps for a short campaign or trial is not necessary but for continuous manufacturing of OPLA films, the proper equipment would be required. NatureWorks recommends the following material for construction for metering gear pumps.

Part	Steel Type
Melt pumps and bearings	SUS440B
Pump blocks	SUS631

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Die

Today, most dies are manufactured by considering the rheology of the resin that will be flowing through them. Since the rheological characteristics of PP and PLA are considerably different, it is unlikely that the die designed for an OPP line will perform as well as one designed for OPLA. This is not to say that the die will not work, it would just not work ideally. This lack of optimum performance will manifest itself as poor gauge control and more difficulty getting the gauge in specification during start up or product changes. In some cases, it may be difficult to achieve proper layer distribution when coextruding films with thin heat seal layers designed for PP. Another factor to consider is the width of the die. The transverse draw ratio of most OPP lines is in the range of 7–10x. PLA will not stretch that far and optimum TD draw ratios are in the range of 3-5x. Therefore, if a die designed for PP is used for PLA, the final film width will be considerably narrower than the normal PP film. A direct result of this is a loss of production capacity. It may also not be possible to move the oven rails close enough to process the film. See more in the TDO section below. While it is not required to change the PP die for a short test or evaluation, any long term production of OPLA film will require a die designed for PLA.

Primary Sheet Pinning

Most OPP lines use an air knife to pin the molten web to the primary chill or casting roll. Since PLA has a much lower melt strength than PP, this method of pinning is unsuitable for PLA and electrostatic pinning is required. PLA is naturally highly polar so no additional pinning agent is required.

Machine Direction Orientation (MDO)

PLA has a natural stretch ratio much lower than PP. MDO stretch ratio for PLA is in the range of 2–4x compared to PP, which is generally in the range of 5–8x. Drives in the MDO section should be capable of operating at the lower stretch ratios. In addition, the stretching temperature of PLA is much lower than PP and the preheating and stretching rolls should be capable of maintaining temperatures in the range of 40–70 C. Both the stretch ratio and stretch temperatures are required for PLA and if the MDO section is not capable of operating at these conditions, the MDO section needs to be modified.

Transverse Direction Orientation (TDO)

Once again, the transverse stretch ratio for PLA is much less than PP. Typically, the maximum TD stretch ratio for PLA is 5 while the minimum stretch ratio for PP is 7. Therefore, the rails of the stretching oven must be able to be adjusted to accommodate the narrower web at the end of the oven. PLA also necks in more during the MD stretching so the oven inlet spacing generally needs to be narrower than for PP. As in the MD stretching, the stretching temperatures are much lower than for PP and the oven must be able to control the preheat temperatures in the 50–70 C range, the stretching temperatures in the 65–80 C range and the heat setting (annealing) temperatures in the 120–140 C range. All of these are required for the production of OPLA film.

Trimming and Edge Trim Recycle

OPLA edge trim has quite different characteristics than PP edge trim and must be handled in a similar manner to OPS edge trim. The high modulus and tendency to split and shatter prevent the conveying of long continuous strips of edge trim from a blade to a remote grinder. The edge trim must be chopped into small pieces approximately 1-inch long with a local chopper located close to the trimming blades. These chopped pieces can then be air conveyed to a grinder for final size reduction. Since PLA present in the edge trim is largely uncrystallized, its melting properties are governed by its Tg which is 55 C. Therefore, introduction of the edge trim back into the extrusion system must be done carefully. There are too many different methods of introducing edge trim back into extrusion to summarize them all here but generally speaking, some modifications will be necessary to the edge trim feeding system of a PP line. In summary, the edge trim removal and chopping system will need to be changed to run PLA and some changes to the feeding system are likely but possibly minimal.

Winding and Tension Control

OPLA film and sheet has a much higher modulus than OPP film and sheet. Furthermore, the material behaves more like a glassy material and does not yield at low stresses. Because of this, the tension control and web temperature of the web between casting and MDO and between MDO and TDO is critical. If the tension is too high, the web can transmit tension back to a point where the material is warm enough to yield which can lead to difficulty in gauge and web width control. Depending upon the lines capabilities, changes to tension control may be required before running PLA. Because PLA has high polarity, excellent static charge dissipation is necessary to eliminate the static charge on the running web.

Cost and Timing

Given the large disparity in machine configurations and scale of production, it is difficult to give a single cost number that would apply across the board for converting an OPP line to run OPLA. However, if all the changes listed above are implemented, the cost for the equipment and installation would be at least 20–30% of the original cost for the installation of the particular line that is being converted. Installation time would be approximately 25–30% of the time used for the original installation of the line. Most of this time would be spent replacing the rails in the TDO oven.

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Safety and Handling Considerations
Material Safety Data (MSD) sheets for PLA polymers are available from NatureWorks LLC. MSD sheets are provided to help customers satisfy their own handling, safety, and disposal needs, and those that may be required by locally applicable health and safety regulations, such as OSHA (U.S.A.), MAK (Germany), or WHMIS (Canada). MSD sheets are updated regularly; therefore, please request and review the most current MSD sheets before handling or using any product.

The following comments apply only to PLA polymers; additives and processing aids used in fabrication and other materials used in finishing steps have their own safe-use profile and must be investigated separately.

Hazards and Handling Precautions
PLA polymers have a very low degree of toxicity and, under normal conditions of use, should pose no unusual problems from incidental ingestion, or eye and skin contact. However, caution is advised when handling, storing, using, or disposing of these resins, and good housekeeping and controlling of dusts are necessary for safe handling of product. Workers should be protected from the possibility of contact with molten resin during fabrication. Handling and fabrication of resins can result in the generation of vapors and dusts that may cause irritation to eyes and the upper respiratory tract. In dusty atmospheres, use an approved dust respirator. Pellets or beads may present a slipping hazard. Good general ventilation of the polymer processing area is recommended. At temperatures exceeding the polymer melt temperature (typically 170ºC), polymer can release fumes, which may contain fragments of the polymer, creating a potential to irritate eyes and mucous membranes. Good general ventilation should be sufficient for most conditions. Local exhaust ventilation is recommended for melt operations. Use safety glasses if there is a potential for exposure to particles which could cause mechanical injury to the eye. If vapor exposure causes eye discomfort, use a full-face respirator. No other precautions other than clean, body-covering clothing should be needed for handling PLA polymers. Use gloves with insulation for thermal protection when exposure to the melt is localized.

Combustibility
PLA polymers will burn. Clear to white smoke is produced when product burns. Toxic fumes are released under conditions of incomplete combustion. Do not permit dust to accumulate. Dust layers can be ignited by spontaneous combustion or other ignition sources. When suspended in air, dust can pose an explosion hazard. Firefighters should wear positive-pressure, self-contained breathing apparatuses and full protective equipment. Water or water fog is the preferred extinguishing medium. Foam, alcohol-resistant foam, carbon dioxide or dry chemicals may also be used. Soak thoroughly with water to cool and prevent re-ignition.

Disposal
DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER. For unused or uncontaminated material, the preferred options include recycling into the process or sending to an industrial composting facility, if available; otherwise, send to an incinerator or other thermal destruction device. For used or contaminated material, the disposal options remain the same, although additional evaluation is required. (For example, in the U.S.A., see 40 CFR, Part 261, "Identification and Listing of Hazardous Waste.") All disposal methods must be in compliance with Federal, State/Provincial, and local laws and regulations.

Environmental Concerns
Generally speaking, lost pellets are not a problem in the environment except under unusual circumstances when they enter the marine environment. They are benign in terms of their physical environmental impact, but if ingested by waterfowl or aquatic life, they may mechanically cause adverse effects. Spills should be minimized, and they should be cleaned up when they happen. Plastics should not be discarded into the ocean or any other body of water.

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